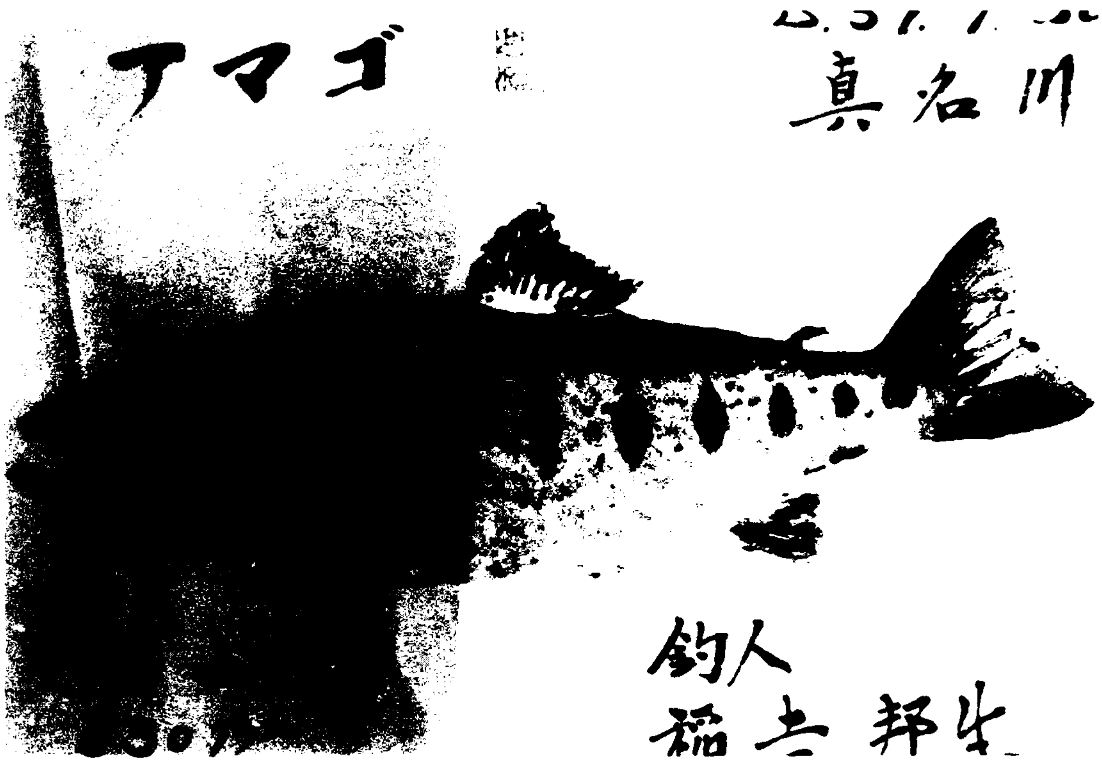
OCTOBER TO DECEMBER 1988

VOL. 13 NO. 4

1

SCIENTIFIC INFORMATION BULLETIN

DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH FAR EAST
DEPARTMENT OF THE AIR FORCE OFFICE OF SCIENTIFIC RESEARCH FAR EAST
UNITED STATES ARMY RESEARCH OFFICE FAR EAST



NAVSO P-3580

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

ADA204778

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.
4 PERFORMING ORGANIZATION REPORT NUMBER(S) ONRFE Vol 13, No. 4	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION ONR/AFOSR/ARO 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION
6c ADDRESS (City, State, and ZIP Code) Liaison Office, Far East APO San Francisco 96503-0007	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING / SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. | PROJECT NO. | TASK NO. | WORK UNIT ACCESSION NO.

11 TITLE (Include Security Classification)

ONR FAR EAST SCIENTIFIC INFORMATION BULLETIN

12 PERSONAL AUTHOR(S)
Arthur F. Findeis, Director; Sandy Kawano, Editor

13a TYPE OF REPORT	13b TIME COVERED FROM ________ TO ________	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
		October-December 1988	

16 SUPPLEMENTARY NOTATION

ISSN: 0271-7077

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Japan	Doping	Air-sea interaction
Superconductors	Band theory	Single crystal films
Oceanography	Mott transition	Metallic multilayers

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONR Far East, the Air Force Office of Scientific Research, and the Army Research Office, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large.

Subscription requests to the Scientific Information Bulletin should be directed to the Superintendent of Documents, Attn: Subscription, Government Printing Office, Washington, DC 20402. The annual subscription charge is: domestic, $11.00; foreign, $13.75. Cost for a single copy is: domestic, $7.00; foreign, $8.75.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION
22a NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code) | 22c OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

18. Subject Terms (continued)

Superconducting thin films
Film growth by sputtering
Technology transfer techniques
Chemical vapor deposition
Superconducting synchrotron
Neutron scattering
Thomas-Fermi screening
Supercomputers
Biomaterials
Film growth by evaporation
Superconducting properties
SiC coatings research
Metallic superlattices
Kuroshio Current research
Hubbard model
Magnetite
Computational fluid dynamics

CONTENTS

Cover: This issue features a photographic reproduction of a fishprint. The Japanese call it "gyotaku," which is a phonetic rendering of two Chinese characters, or kanji: gyo, meaning fish, and taku, meaning print. In a way this printmaking is similar to brass rubbing or tombstone rubbing: a sheet of pliable paper is spread over the object; molded to the contours by light finger pressure; and surface shaded or rubbed by soft pencil, charcoal, or crayon. Anglers initiated this custom as a means of recording their prize catches. Gyotaku is uniquely Japanese, being developed and recognized in Japan. In 1955 an association was formed to exhibit and promote this as an art form. Some of the first works exhibited outside Japan were displayed in June 1956 at the American Museum of Natural History. Courtesy of E.M. Lenoe.

HIGH TEMPERATURE SUPERCONDUCTING THIN FILMS IN JAPAN

Michael Osofsky, Phillip R. Broussard, and Earl Callen

The study of thin films of the new high temperature superconductors can address a wide range of scientific questions and may well lead to many vital technological applications. We review the fundamentals of high temperature superconducting thin films: their structure, how their physical and superconducting properties are characterized, and how they are made. We then describe facilities and programs of several Japanese superconducting thin film groups.

INTRODUCTION

One of the most sought after commercializations of the new high temperature superconductors will be in electronics--detectors, switches, logic devices, interconnects, and mixers. Some of these applications can be realized with pure superconducting elements. Others will be hybrid semiconductor-superconductor devices, interfacing the new materials with silicon or with gallium arsenide. Thin superconducting films deposited onto a passive substrate, onto a semiconducting device, or on an intermediate buffer layer are a natural way to achieve this goal. Factors such as film stoichiometry, crystalline orientation, homogeneity, surface smoothness, and substrate interaction impact on these applications and must be optimized. Many Japanese laboratories have considerable experience in both semiconducting and superconducting thin film technology which they are exploiting in high T_c development. In this article we sketch some of the basics of film growth and then describe activities, facilities, and programs at several Japanese laboratories--Kyoto University, the Nippon Telephone and Telegraph (NTT) Electrical Communications Laboratory at Ibaraki, the National Research Institute for Metals at Tsukuba, the Electrotechnical Laboratory at Tsukuba, Sumitomo Electric Company in Itami City, Osaka University, and Matsushita Electric Company in Osaka.

THIN FILM TECHNOLOGY

Structure

The structures of the high temperature superconducting compounds are related to the barium titanate or simple perovskite unit cell (Figure 1). In this structure oxygen atoms, in an octahedral configuration, surround a metal ion that is at the center of a cube of cations. Figure 2 shows the structures of several of the new superconductors. Key components are copper-oxygen sheets separated by other cations.

Growth of Superconducting Thin Films

We will concentrate on two techniques, evaporation and sputtering (Ref 1), which produce films less than or equal to 1 μm thick. Both techniques deposit atoms of the desired compound onto hot or cold substrates and may include a postevaporation anneal. The process must achieve uniform and correct composition, crystal

structure, and oxygen content throughout the entire film while avoiding reactions with the substrate.

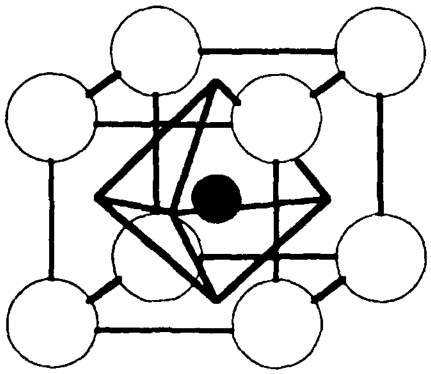


Figure 1. The simple perovskite (or barium titanate) unit cell. Oxygen atoms are positioned at the vertices of the octahedron.

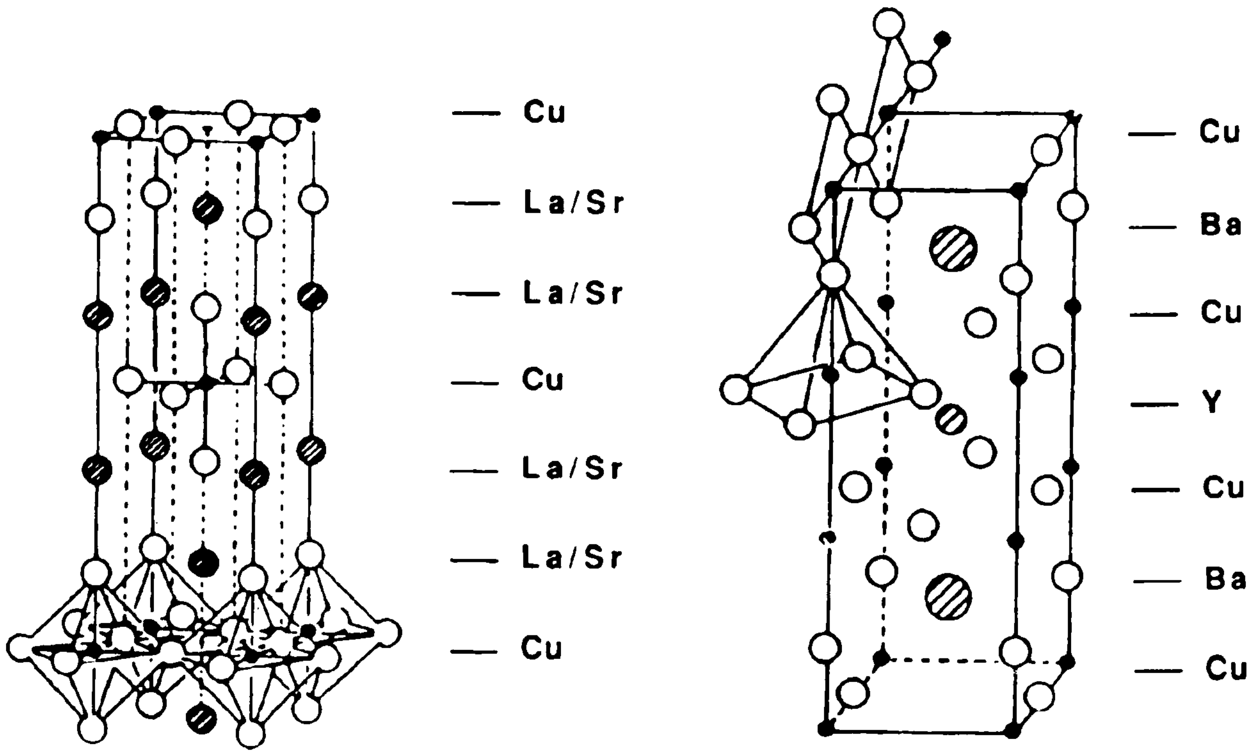
The most commonly used substrates are single crystals of strontium titanate ($SrTiO_3$), magnesium oxide (MgO), and yttria-stabilized zirconia (YSZ). These compounds are cubic with lattice parameters of 3.905, 4.203, and 5.16 Å, respectively, and do not detrimentally interact with the superconductors. Films have been made on other materials such as sapphire, lithium niobate, and even silicon, but they are plagued by substrate interaction problems.

Deposition onto a hot substrate (usually 600 °C and above) in the presence of oxygen (partial pressures up to 1 mTorr) can produce in-situ growth of the superconducting phase. At present many of these films must still be postannealed. Epitaxial films grown in this manner have the best superconducting properties. One problem with this technique is that the introduction of oxygen into deposition systems reduces the operating life of heaters and filaments. Deposition onto a substrate at ambient temperature and low oxygen partial pressure (10^{-5} to 10^{-6} Torr) produces insulating, amorphous films that must be postannealed in oxygen to achieve superconducting properties.

We will give only generic descriptions of growth techniques and will not describe annealing schedules since there are as many procedures as there are research groups.

Evaporation. In general, film growth by evaporation uses separate sources for each element to avoid preferential evaporation of the higher vapor pressure species (Figure 3). The rates of all sources must be monitored and precisely controlled to produce stoichiometric compositions. This is accomplished through the use of quartz crystal rate monitors in a feedback control loop. The two most commonly used evaporation sources are resistively heated "ovens" (Knudsen cells or "K-cells") and electron beam sources (e-guns). In resistively heated sources large electric currents heat a filament that surrounds a container filled with the material. E-guns heat the material via a focused electron beam. The beam rasters across the target to prevent pits from developing and modulating the evaporation rate. Generally e-guns are used on lower vapor pressure materials and thermal sources for the high vapor pressure materials.

Sputtering. In the sputtering process (Figure 4) a target under bombardment by ions of a plasma (usually argon) ejects material that deposits onto a substrate. The target composition usually deviates from the desired film composition. The amount of this deviation, peculiar to each system, must be discovered by trial and error. The plasma is excited either by rf radiation or a large dc potential difference. The process is usually aided by the placement of magnets to confine electrons near the target (so-called magnetron sputtering). Sputtering has the advantage that a composite target can be used, which removes the need for active rate control during deposition. Some systems use multiple sputter-guns in a manner analogous to the evaporation configuration but with much better rate control. In addition, adding oxygen to the sputtering gas is a natural way to enhance the oxidation of the film during deposition. However, some oxygen becomes negatively ionized and bombards the substrate, which resputters film components.



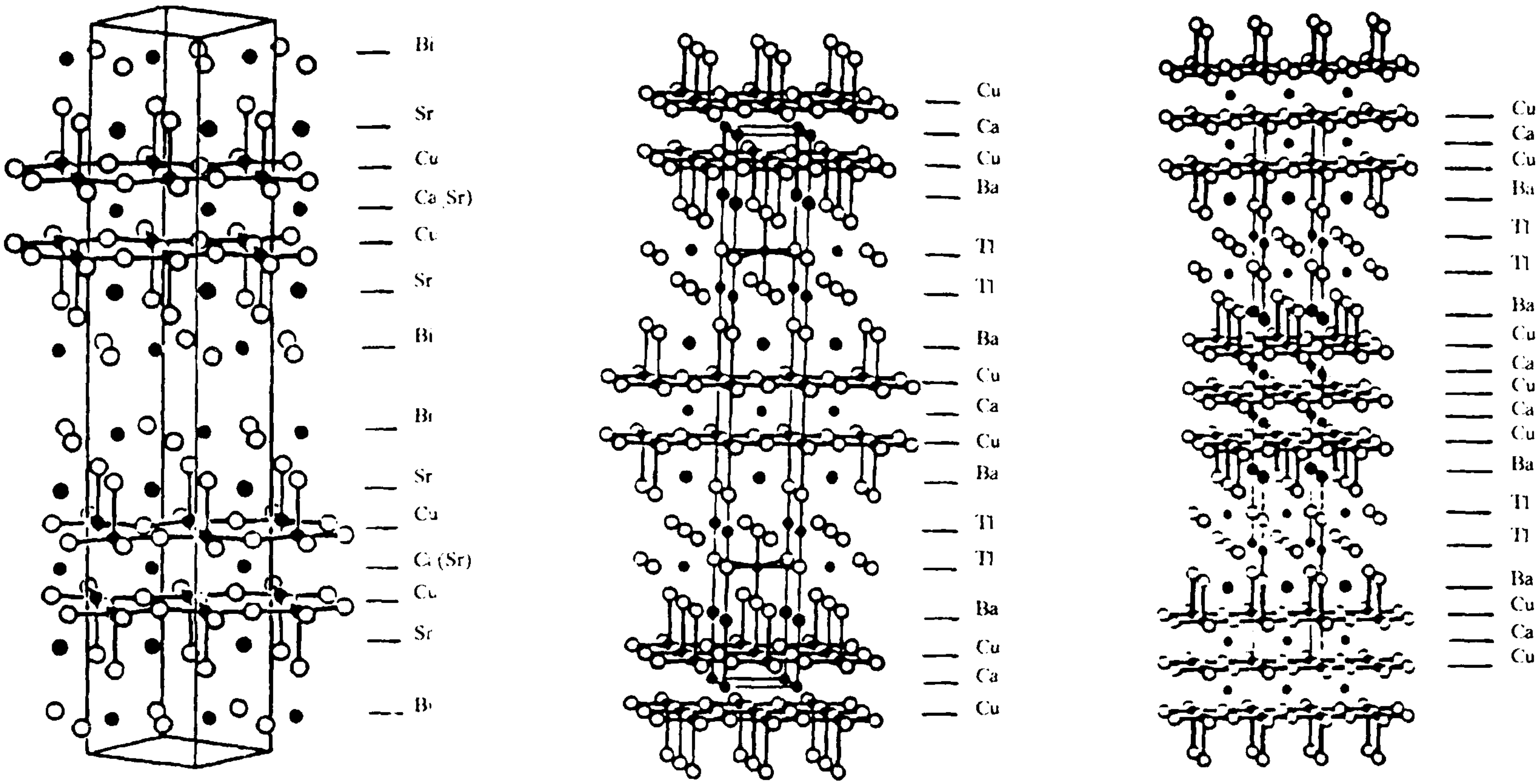
$La_{2-x}Sr_xCuO_4$

Tetragonal (I4/mmm)
a = 3.7873(1), c = 13.2883(3)

$YBa_2Cu_3O_7$

Orthorhombic (Pmmm)
a = 3.8185(4), b = 3.8856(3),
c = 11.6804(7)

Figure 2. The structure of several of the high temperature superconductors: $La_{2-x}Sr_xCuO_4$, with $T_c \simeq 40$ K ($x = 0.15$); $YBa_2Cu_3O_7$, with $T_c \simeq 95$ K; $Bi_2Sr_2CaCu_2O_8$, with $T_c \simeq 85$ K; $Tl_2Ba_2CaCu_2O_8$, with $T_c \simeq 85$ K; $Tl_2Ba_2Ca_2Cu_3O_{10}$, with $T_c \simeq 110$ K. There is also a $Bi_2Sr_2Ca_2Cu_3O_{10}$, with structure similar to the Tl compound and $T_c \simeq 110$ K. The unshaded circles represent oxygen atoms.



$Bi_2Sr_2CaCu_2O_8$

Orthorhombic (Amaa)
a = 5.399(2) (x=5)
b = 5.414(1)
c = 30.904(16)Å (subcell)

$Tl_2Ba_2CaCu_2O_8$

Tetragonal (14/mmm)
a = 3.855(1)
c = 29.330(5)Å

$Tl_2Ba_2Ca_2Cu_3O_{10}$

Tetragonal (14/mmm)
a = 3.851(1)
c = 35.[illegible]3(6)Å

Figure 2. Continued.

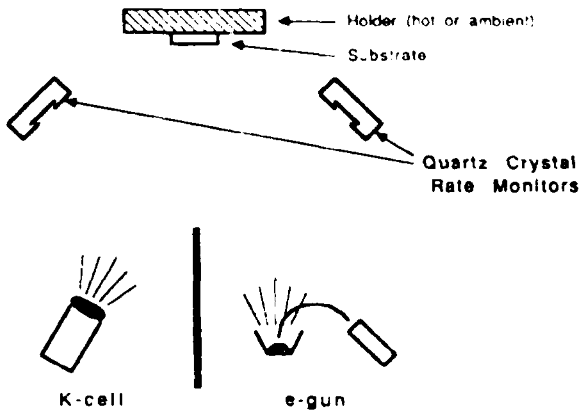


Figure 3. Schematic of a thin film evaporation system with e-gun and K-cell sources. High T_c systems typically have three sources.

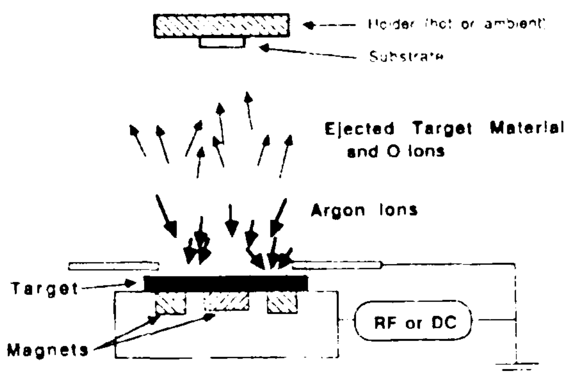


Figure 4. Schematic of a single-target sputtering system.

Characterization

What is a "good" film? The answer depends on the film's intended application. If one wants to study the properties of the superconductor then a good film has the right stoichiometry and oxygen content and is an epitaxial single crystal with the correct crystal structure. This film will have low normal state resistivity, a sharp resistive superconducting transition at a high temperature, be highly anisotropic in its macroscopic properties, and show complete magnetic flux expulsion (Meissner effect) below the transition. On the other hand, if the film is to be used as an infrared radiation detector, it must be polycrystalline and have a broad transition (Ref 2).

The task of characterizing superconducting thin films can be divided into two broad interrelated categories: materials properties and superconducting properties. Obviously, materials properties strongly influence the superconducting characteristics of the film.

Materials Properties. The important materials properties of thin films are cation composition, oxygen content, homogeneity, crystal structure, alignment, and gross morphology. The most common tools used to analyze these properties are optical microscopy, transmission and scanning electron microscopy (TEM and SEM), energy dispersive spectroscopy (EDS), microprobe analysis, and x-ray diffraction (XRD).

Optical microscopy with polarized light efficiently provides a simple picture of the gross morphology of a film, with 1 micron spatial resolution. One can readily observe the average grain size, the fraction of extraneous phases, orientations of the grains, and the presence of large defect structures such as twins. Figure 5 shows a polarized light micrograph of a patterned $YBa_2Cu_3O_x$ film. We can see the general texture of the film: grain orientation, grain alignment, and grain size. In addition, though not shown in this black and white picture, the grain color in polarized light can indicate secondary phases and the superconducting phase (Ref 3).

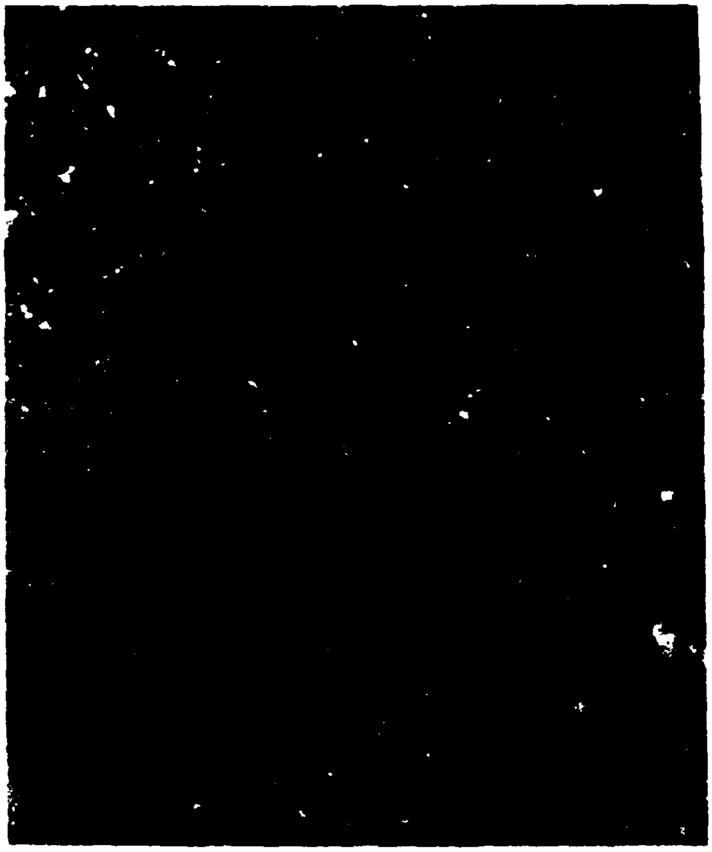


Figure 5. Polarized light micrograph of a patterned $YBa_2Cu_3O_7$ film magnified 1,000 times.

SEM shows details on scales from a few microns down to 1,000 Å, while TEM can resolve features down to 2 Å. Figure 6 is an SEM micrograph of the film in Figure 5. The greater detail shows that the aligned and oriented grains form a network throughout the film. This network makes it difficult to precisely determine the film's resistivity and critical current density.

When an electron beam bombards a material, x rays with energies characteristic of the constituent elements are excited. The electron microprobe and the EDS feature of electron microscopy detect the energies and wavelengths of the emitted radiation in order to identify the constituents (and their homogeneity) on micron length scales. Figure 7 shows the SEM image of a film of Bi-Sr-Ca-Cu-O. By a bismuth dot map one can reveal the relative concentrations of the constituent elements on the film surface.

X-ray diffraction is the standard method for identifying crystal structure and grain orientation. A diffraction event consists of two pieces of information that relate to the crystal structure: the angle at which it occurs and how intense it is. The former provides information about the lattice--its symmetry and unit cell parameters. The latter can be analyzed in terms of the

arrangement of atoms within the unit cell and atomic form factors--the x-ray scattering powers of atoms of the various elements. Analysis of the pattern of a single crystal or single-crystal film allows one to determine the crystal structure. If the film is polycrystalline with aligned crystallites one can calculate the degree of alignment from the width of the intensity maxima.

Figure 6. SEM micrograph of the film in Figure 5 magnified 3,000 times. The 11 dots at the bottom of the picture span 10 microns in the micrograph field.

Figure 7. SEM micrograph of a Bi-Sr-Ca-Cu-O film magnified 4,000 times.

Two x-ray techniques commonly used for the study of thin films are automated diffractometry scans and photographic techniques (Read photography). In each case the sample is illuminated with filtered radiation and the diffracted x rays recorded. On the diffractometer the scattered radiation in a single plane is electronically recorded as a function of diffraction angle. The photographic technique yields less precise data but has the advantage of simultaneously recording much of the diffracted radiation from the sample surface, thus giving a large picture of sample morphology.

Figure 8 shows a diffraction spectrum of a bulk polycrystalline sample of $YBa_2Cu_3O_x$. Figure 9 shows the spectrum of a highly oriented $YBa_2Cu_3O_x$ film with the c-axis perpendicular to the substrate surface. Missing reflections indicate that the film is oriented. These patterns correspond to the "123" crystal structure in Figure 2.

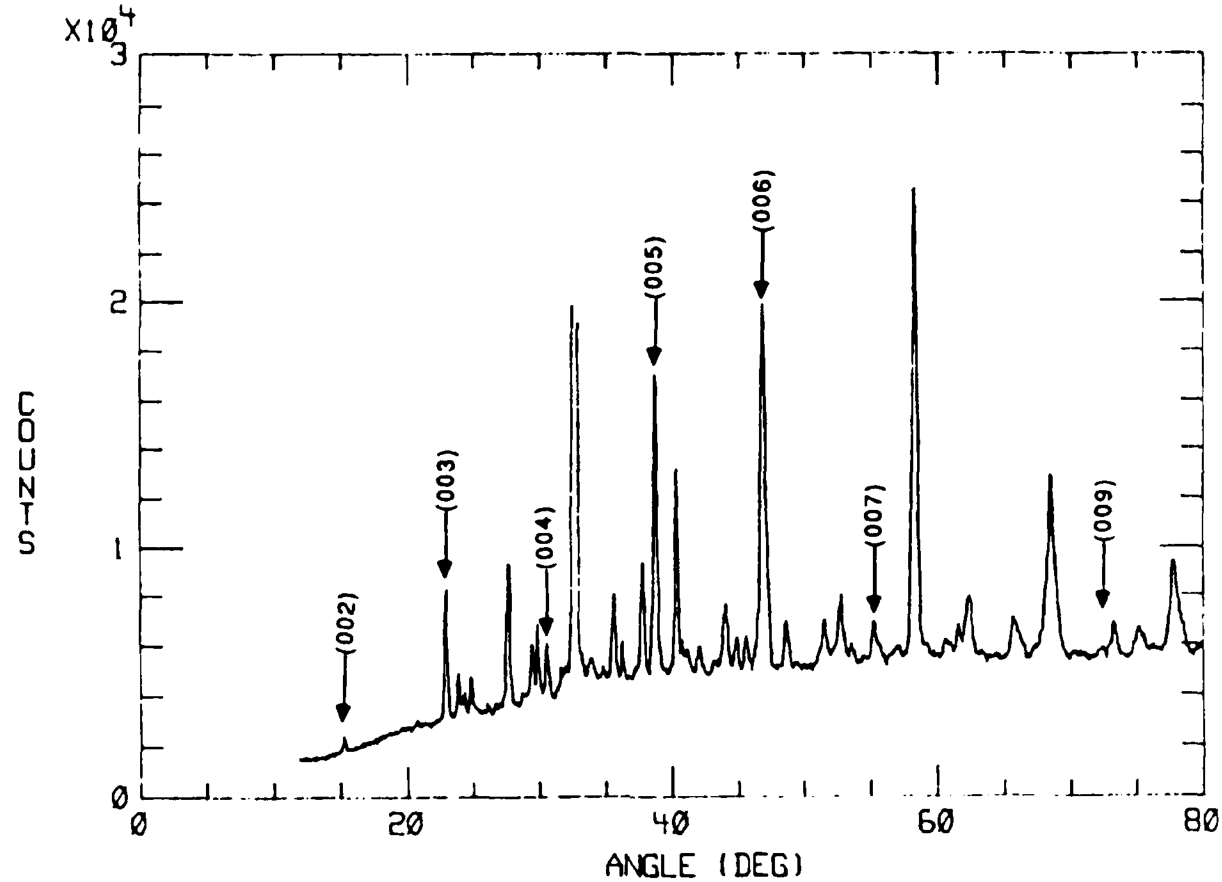


Figure 8. X-ray diffraction spectrum of an unoriented polycrystalline bulk sample of $YBa_2Cu_3O_7$. Several of the (00L) reflections, i.e., those from the c-axis, are labelled. The other peaks are due to reflections from other crystal orientations.

Figure 10 shows the configuration for the Read technique (Ref 4). X rays impinge on the film at a glancing angle so as to illuminate a large portion of the surface. The scattered radiation is recorded on photographic film, which forms a cylinder surrounding the specimen. Figure 11 is a Read photograph of a Bi-Sr-Ca-Cu-O film on (100) MgO, oriented with the c-axis perpendicular to the film surface. The most intense peaks are reflections of the MgO substrate. The labelled point intensity peaks are from the film and indicate its highly oriented nature (which is in registry with the substrate). Descriptions of the techniques of x-ray crystallography can be found in the literature (Ref 5).

An analogous electron diffraction technique is reflection high energy electron diffraction (RHEED). An electron beam hits the film at a glancing angle and diffracted electrons are detected by a phosphor screen. This technique probes only the film surface and is generally used in situ during film growth. A polycrystalline film shows rings on the screen, an oriented film with a rough surface appears as spots, and an oriented film with a smooth surface appears as straight streaks (Ref 6,7).

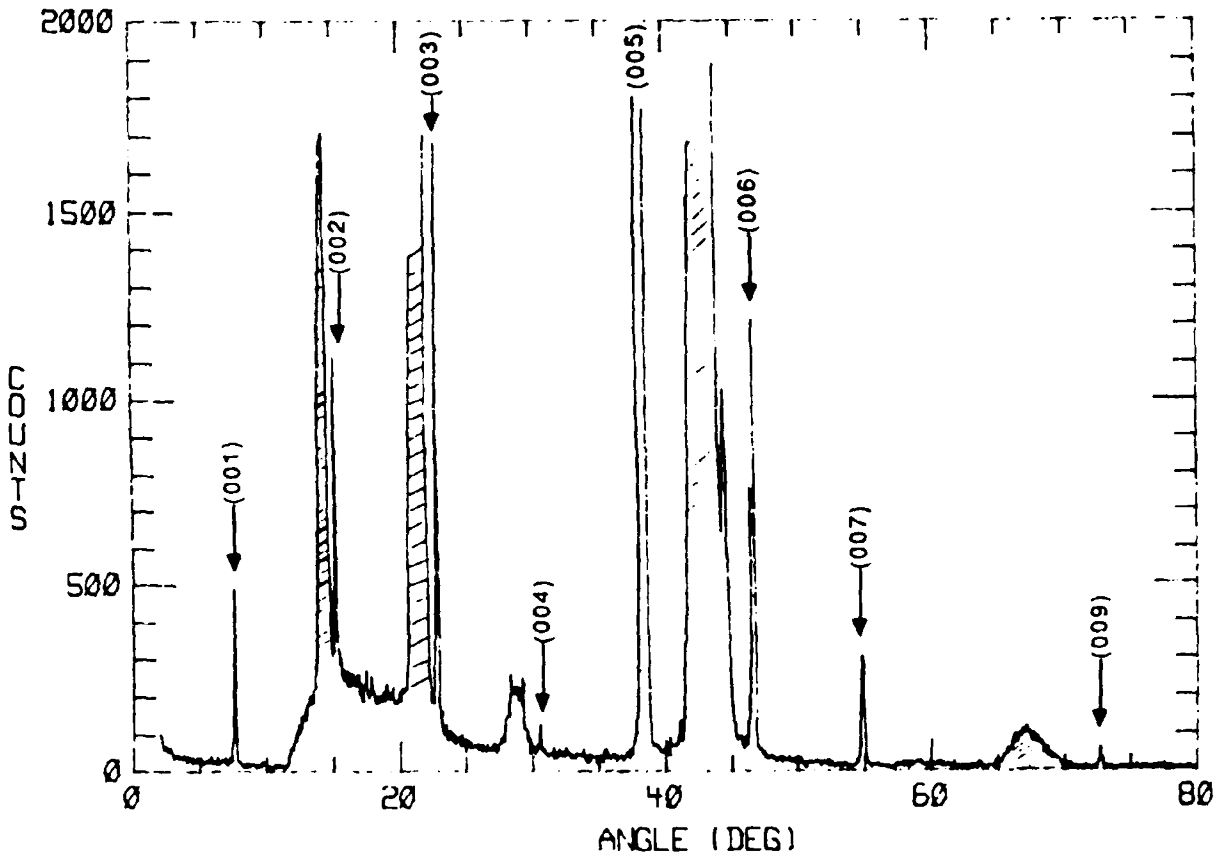


Figure 9. X-ray diffraction spectrum of a $YBa_2Cu_3O_7$ film oriented with the c-axis perpendicular to the film surface. Several of the (00L) reflections are labelled. The oriented nature is evident from the sharpness of the peaks and the absence of other reflections. The shaded peaks are from the single-crystal MgO substrate.

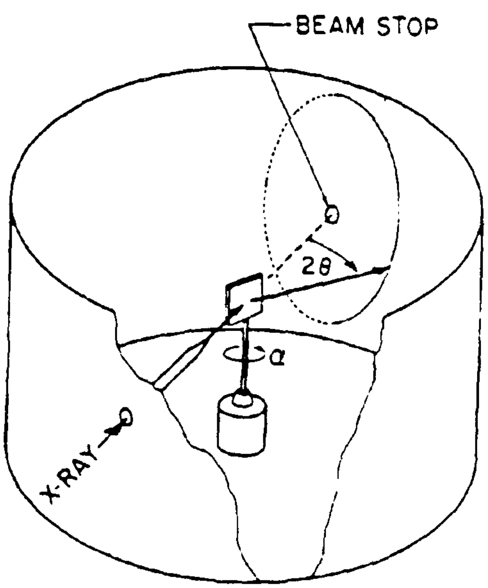


Figure 10. Configuration for the Read technique. Photographic film lines the inside of the cylinder (from Ref 4).

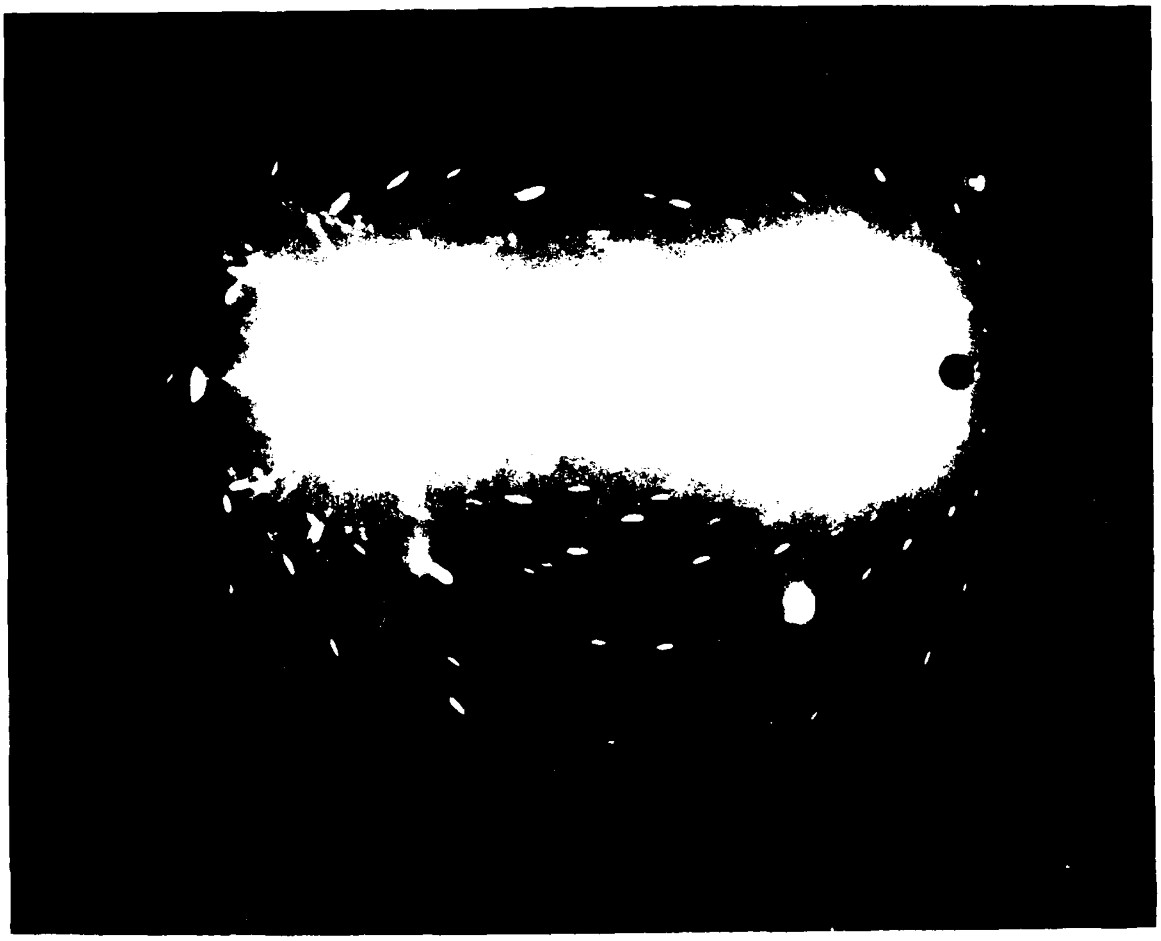


Figure 11. Read photograph of a Bi-Sr-Ca-Cu-O film with the c-axis oriented perpendicular to the film surface. The bright spots are reflections from the single-crystal MgO substrate. The dim spots (labelled with reverse letters) are reflections from the film.

Superconducting Properties. The best known characteristic of a superconductor is the absence of electrical resistance below the transition temperature. Measurements of the resistance are made using a standard four-probe technique (Figure 12). Four leads are attached to the sample (typically with solder, silver paint, or pressure contacts) and current is passed through the outer leads. The voltage drop is detected at the inner two leads, from which the resistance (and resistivity if the sample geometry is known) can be calculated. Figure 13 shows the resistive transition for $YBa_2Cu_3O_x$ films on $SrTiO_3$ and on MgO. The transition occurs at 93 K (with a width ≈ 1 K) on the $SrTiO_3$ substrate and at about 80 K (with a width of 5 K) on the MgO. (It is not clear why $YBa_2Cu_3O_x$ films on MgO have lower T_cs than those on $SrTiO_3$.)

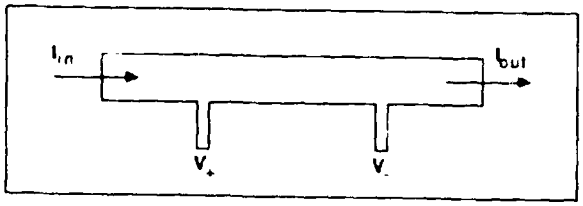


Figure 12. Four-probe resistance configuration.

With this technique one can establish an upper bound on the resistance, but of course one cannot ascertain that the resistance is actually zero. Plots of resistivity versus temperature only show where the resistivity falls below the limit of detectability (typically 10^{-10} ohm-cm). By "R = 0" we mean the resistance is below instrumental sensitivity. More sophisticated techniques (Ref 8) have shown that the resistivity of the "123" material is less than 10^{-18} ohm-cm at 77 K.

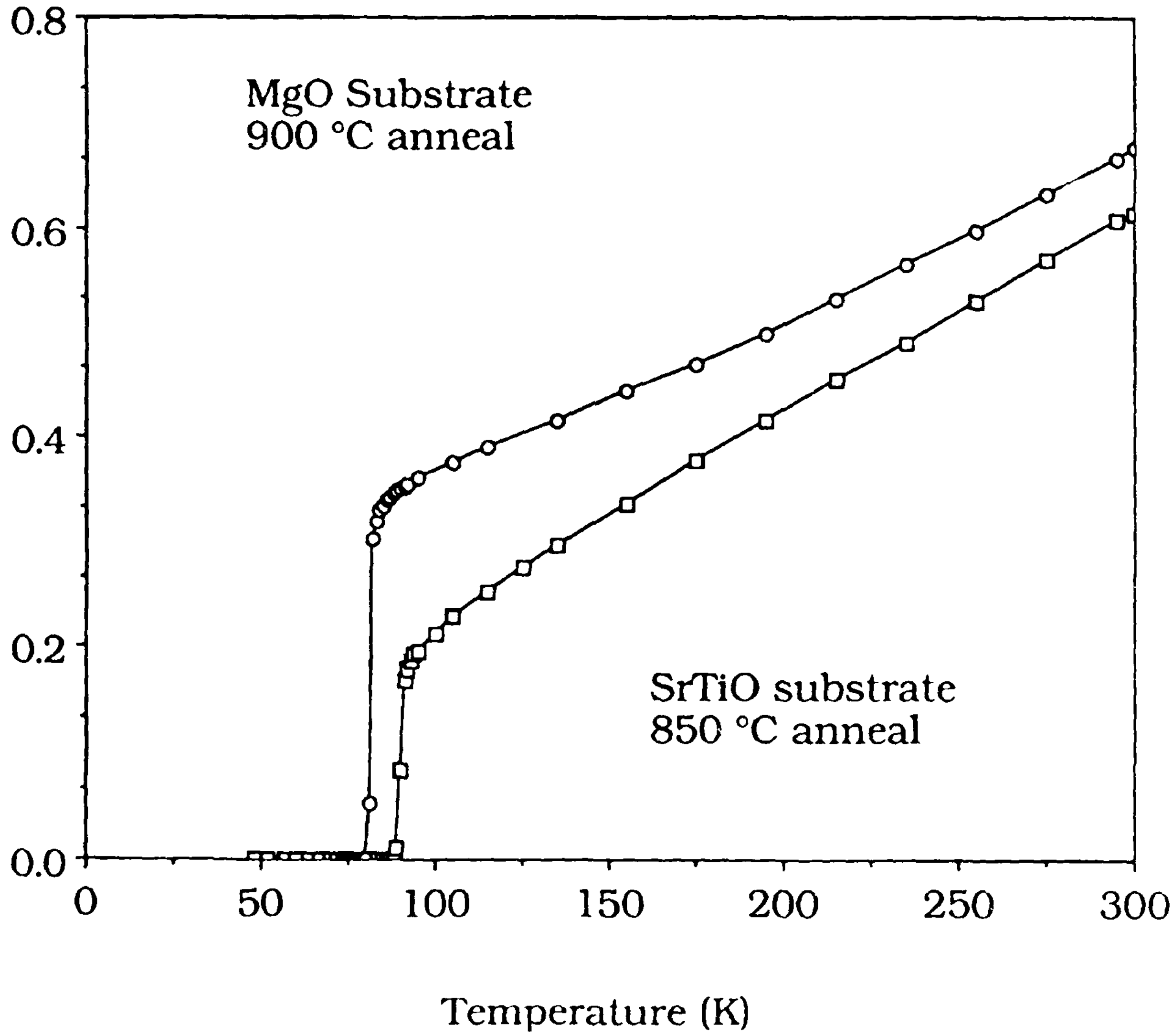


Figure 13. Resistivity versus temperature curves for films of $YBa_2Cu_3O_7$ on MgO and $SrTiO_3$. The film of $SrTiO_3$ is pictured in Figures 5 and 6.

Superconductors exclude magnetic flux (the Meissner effect), but sufficiently large magnetic fields destroy superconductivity (Ref 9). There are two kinds of superconductors: type I and type II. In ideal type I superconductors there is a critical magnetic field, H_c, below which all flux is expelled (from a thin rod parallel to the field) and above which the superconductivity is destroyed. The high T_c materials are type II superconductors. In these superconductors there are lower and upper critical magnetic fields, H_{c1} and H_{c2}. Fields whose strength is below H_{c1} are totally excluded, just as in type I superconductors. In fields larger than H_{c1} but smaller than H_{c2} the system is in the mixed state, in which flux penetrates in the form of a lattice of normal (nonsuperconductor) cores surrounded by vortices of supercurrent. At H_{c2} flux penetrates the entire sample, which is then completely normal. In these new materials H_{c1} at 4 K is typically 300 to 500 gauss (G) and H_{c2} is 10^5 to 10^6 G.

The self fields generated by large currents drive superconductors into the mixed state, with the cores (and therefore the fluxoids) pinned to material imperfections. The transport current exerts Lorentz forces on the cores, which remain immobile as long as the pinning forces are not exceeded. When the pinning forces are overcome by the Lorentz forces, the cores move. Irreversible work is then done by the transport current and energy is dissipated; i.e., there is finite resistance in the superconductor. The current density at which this occurs is called the critical current density, J_c. This is an important quantity for those technological applications where films must carry large currents. A good film has a J_c of 10^6 A/cm^2 at 4 K in zero magnetic field and is relatively insensitive to increasing temperature and field strength (except close to T_c). Figures 14 and 15 show plots of J_c as a function of temperature and of field for the highly oriented "123" film described above.

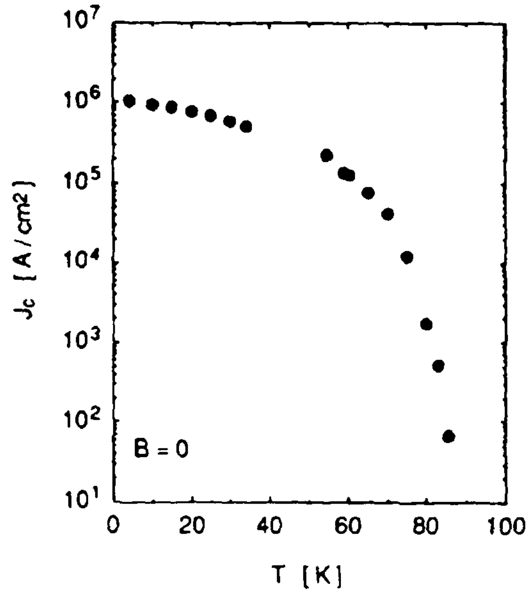


Figure 14. Critical current density versus temperature at ambient (Earth) magnetic field for the film pictured in Figures 5 and 6.

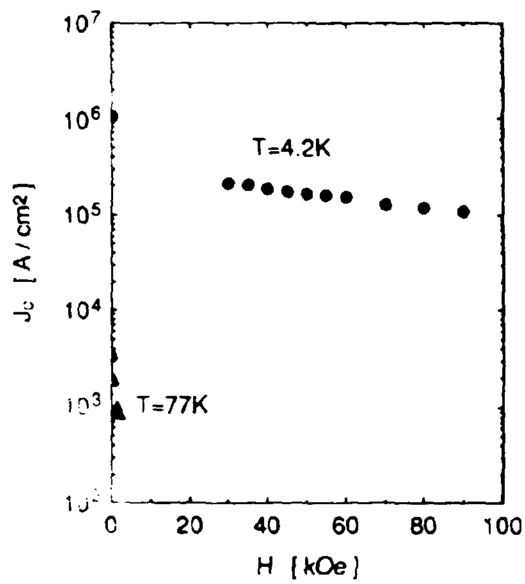


Figure 15. Critical current density versus magnetic field strength for the film pictured in Figures 5 and 6.

The Importance of Thin Films

Oriented or single crystal thin films provide a means to study the anisotropic nature of the high temperature superconductors. As Figure 2 shows, the unit cell of the "123" material has $c/a \simeq 3$. The newer bismuth- and thallium-based superconductors have ratios from 4.5 to 9, with corresponding T_cs from 20 to 125 K. Electrical and magnetic properties are different in the a and c directions and possibly in the a and b directions. Electrical transport (i.e., resistivity and critical current), magnetic susceptibility, x-ray, and optical (i.e., reflectance and absorption) measurements are tools that are sensitive to the anisotropy. Film growth also allows the possibility of multiple layering to produce tunnel junctions and proximity effect systems. Such geometries will allow the study of anisotropic tunnel junctions and proximity effect devices consisting of layers of high T_c superconductors with normal metals, semiconductors, or other superconductors (Ref 9: Schuller, Tachiki, and Callen).

Technologically, thin films are the major avenue through which superconductors can be coupled with semiconductors. The high temperatures needed to form superconducting films degrade the semiconductor-high T_c superconductor system, so it is clear that hybrid electronic applications will require lower temperature processing schedules. Once this problem is overcome, the ability to interface the two technologies in the temperature range where both are capable of high performance will lead to powerful devices. Traditional superconducting devices such as superconductor-normal-superconductor (SNS) mixers (Ref 10), superconducting quantum interference devices (SQUIDS) (Ref 11), as well as new hybrid devices operating at 77 K offer a new generation of technology while avoiding the difficulties of operating at very low temperatures.

The Japanese are mounting a substantial effort to develop high T_c thin film technology with a strong emphasis on applications. We report now on visits to several laboratories.

JAPANESE LABORATORIES

Kyoto University

The group at the Institute for Chemical Research, led by Professor Y. Bando, is growing single crystal films of $YBa_2Cu_3O_x$ on (100) and (110) $SrTiO_3$ by activated reactive evaporation, that is, in an oxygen plasma (Ref 12). The films are grown by coevaporation from three metal sources onto 500- to 650-°C substrates at rates of 4 to 6 Å/s. The films are deposited with the a-b plane parallel to the surface on the (100) substrate and with the (110) or (103) planes parallel to the surface on the (110) substrate. RHEED studies show the films to be single crystals.

Following a postanneal at 500 °C for 1 hour in oxygen, the resistance of the films in the a-b plane orientation becomes negligible at 90.2 K with a width of 1.7 K. A film as thin as 100 Å showed a transition at 82 K. The J_c of a 1,000-Å film at 77 K was a respectable 4×10^6 A/cm². This work is significant because it shows that epitaxial films with high critical currents can be grown without the high temperature anneals (800 °C) commonly used in other laboratories.

Contact: **Prof. Yoshichika Bando**; Institute for Chemical Research, Kyoto University, Uji, Kyoto-fu 611, Japan.

Nippon Telephone and Telegraph (NTT) Electrical Communications Laboratory, Ibaraki

The NTT Ibaraki group is mounting a substantial effort in the growth of "123" bismuth-based films as well as films of the original "214" 40-K superconductor.

$La_{2-x}Sr_xCuO_4$. Single-crystal "214" films (x=0.1) are epitaxially grown with a single-target, rf magnetron sputtering system depositing at 120 Å/min onto $SrTiO_3$ (100) and (110) substrates at 800 °C. After deposition the films are annealed at 800 °C for 8 hours in air. The films grow in the (001) orientation on the (100) substrate and in the (103) orientation on the (110) substrate.

These films are patterned with dilute acid for Hall effect and resistivity measurements. Deconvolution of the measurements on films of several different orientations shows that the resistivity is about the same in the a and b directions. At 300 K the resistivity in the c direction is about 20 times less than in the a and b directions and at 40 K about 30 times less. The upper critical field, H_{c2}, with the field parallel to the c-axis, is 5.2 times that perpendicular. The Hall coefficient, R_H, which is proportional to the inverse of the number of carriers, is positive in all directions, indicating the dominance of hole carriers. (This contrasts with the "123" materials, which are holelike in the a-b plane and electronlike in the c direction.) The Hall coefficient in the a-b plane is four times that in the c direction. Superconducting transitions are broad, with resistivity onsets at around 40 K and negligible resistance only below 15 to 18 K, depending on the sample.

$YBa_2Cu_3O_x$. Films of "123" are evaporated from metals in K-cells in the presence of ionic oxygen onto (100) and (110) $SrTiO_3$ at 700 °C. The Bell Labs method (Ref 13) of replacing barium metal with barium fluoride is used to better control the barium concentration. So far, attempts at epitaxial growth with no postanneal are off stoichiometry and have some bad spots. The transitions are broad with negligible resistance at 82 K. This may be due to fluorine left in the film from the barium fluoride. Films on the (110) substrate have rough surfaces while those on the (001) substrate are smooth. This characteristic is important since surfaces must be smooth for device applications.

Films are also deposited in situ with rf magnetron sputtering from a single target (adjusting the Cu concentration with pellets or a second Cu target) onto 600-°C $SrTiO_3$ and sapphire substrates. A most impressive result is a 3,000-Å-thick, c-axis-oriented $EuBa_2Cu_3O_x$ film deposited at 650 °C onto sapphire. With no postanneal this film has negligible resistance at 80 K. This is an important result for applications since sapphire has better dielectric properties than $SrTiO_3$ and again shows that high temperature postanneals are not necessary.

Bismuth Superconductor. Films of the bismuth-based superconductor are sputtered onto MgO at 580 °C in a 50-percent oxygen/argon plasma from a $BiSrCaCu_{1.5}O_x$ target. As-grown films have "zero resistance" at 56 K, and after an 880-°C postanneal, at 90 K. X-ray diffraction shows the presence of the 85-K phase with $c \simeq 30$ Å and of the 110-K phase with $c \simeq 36$ Å.

Exploratory Devices. Simple techniques for making junctions are being explored. The NTT group has grown a multilayer system consisting of a 3,000-Å $EuBa_2Cu_3O_x$ layer, 30-Å Al_2O_3 barrier layer, and 1,000-Å (110) niobium layer. X-ray analysis shows the system to be epitaxial. Resistance measurements show a T_c of 75 K, but as of June 1988 junctions still had pinhole and surface roughness problems. A 5x2 micron microbridge was patterned by argon milling to make a SQUID. The device has a J_c of about 4×10^3 A/cm² at 4.2 K and shows granular behavior including rf-induced voltage steps in the I-V curve typical of Josephson junctions.

Contacts: Y. Enomoto, O. Michikami, T. Murakami, M. Suzuki; Nippon Telephone and Telegraph Electrical Communications Laboratory, Tokai, Ibaraki 319-11, Japan.

National Research Institute for Metals (NRIM), Tsukuba Laboratories

This laboratory is well known for developing superconducting magnet wires of conventional superconductors (Ref 14), and H. Sekine and coworkers are now developing wires of the high T_c superconductors. The group is also well known for the discovery by Maeda et al. of the bulk Bi-Sr-Ca-Cu-O superconductor (Ref 15). M. Fukutomi is leading the effort to deposit films of this material. Films are rf magnetron sputtered from a single sintered target of $Bi_{1.3}SrCaCu_{1.5}O_x$ in 3×10^{-2} Torr of argon onto (100) MgO. Substrate temperature is carefully controlled while sputtering: 800 °C for the first 10 to 15 minutes and then at between 700 and 740 °C for the rest of the deposition. The as-grown films have "R = 0" below 70 K. A postanneal at 880 °C for one-half hour in ionic oxygen followed by a slow cool raises the "R = 0" temperature to 100 to 103 K. SEM observation after the high temperature deposition reveals what appears to be a film solidified from a melt. Fukutomi proposes that the films grow from a molten layer. The films are not uniform over the entire area of the substrate. X-ray analysis shows the major component to be the 85-K phase with $c \approx 30$ Å. The films are highly oriented with the c-axis perpendicular to the surface. X-ray analysis also indicates the presence of the high temperature phase with $c \approx 37$ Å.

Contacts: M. Fukutomi, **Hiroshi Maeda**, H. Sekine, T. Takeuchi, Yoshiaki Tanaka, H. Wada; National Research Institute for Metals, 1-2-1 Sengen, Tsukuba-shi, Ibaraki-ken 305, Japan.

Electrotechnical Laboratory (ETL), Tsukuba

A joint government-industry-university group is sputtering Y-based "123" from stoichiometric targets (Ref 16). They deposit 3,000- to 8,000-Å films on (100) MgO and $SiTiO_3$ at 500 to 650 °C using a conventional rf diode system with a 1:1 argon:oxygen atmosphere. A common problem with the sputtering technique is that the stoichiometry of the deposited film usually differs from that of the target. The ETL group solves this problem by isolating the substrate from the flux of negative ions and secondary electrons. They believe that ion bombardment weakens the Ba-O and Cu-O bonds of the growing film, resulting in the deficiencies in barium and copper observed in films that are not isolated from the ion flux. The stoichiometry of films

grown in the isolated configuration, as measured with EPMA (electron-microprobe) and other methods, matches that of the "123" target for a wide range of chamber pressures and substrate temperatures. The best filr : are grown at 580°C and low pressure (less than 10 mTorr) to reduce surface roughness. The films have (100) orientation as grown, less than 20-Å surface features (as determined by SEM and a commercial stylus instrument), and resistive onsets around 85 K, with "R = 0" a little above 80 K.

Contacts: **H. Ihara, K. Murata, N. Terada, M. Tokumoto**; Electrotechnical Laboratory, 1-1-4 Umezono, Sakura, Niihari, Ibaraki-ken 305, Japan.

Sumitomo Electric Industries, Itami City

This group, led by Dr. H. Itozaki, makes rf-sputtered films of $REBa_2Cu_3O_x$ with RE=Y, La, Nd, Sm, Eu, Gd, Dy, Ho, Er, and Yb on (001) MgO (Ref 17). The substrates are at 400 to 800 °C, the atmosphere is 80 percent argon/20 percent oxygen, and the target stoichiometries are 1:2.2:3.4 (RE:Ba:Cu). Their 7,000-Å films grow at about 20 to 50 Å/min. By carefully adjusting the sputtering conditions the Sumitomo group can deposit RE=Er, Y, Ho, and Dy films onto 750-°C substrates. The films are metallic, oriented with their c-axes perpendicular to the surface, and have T_cs above 80 K. Gd, Eu, and Sm films deposited on substrates at temperatures exceeding 790°C also have these properties.

Epitaxial growth of the Ho "123" system has been carefully studied (Ref 17,18). Figure 16 summarizes the results of the substrate heating and postanneal studies by the Sumitomo group. The important conclusion is that the substrate must be above 600 °C during deposition to achieve epitaxial growth.

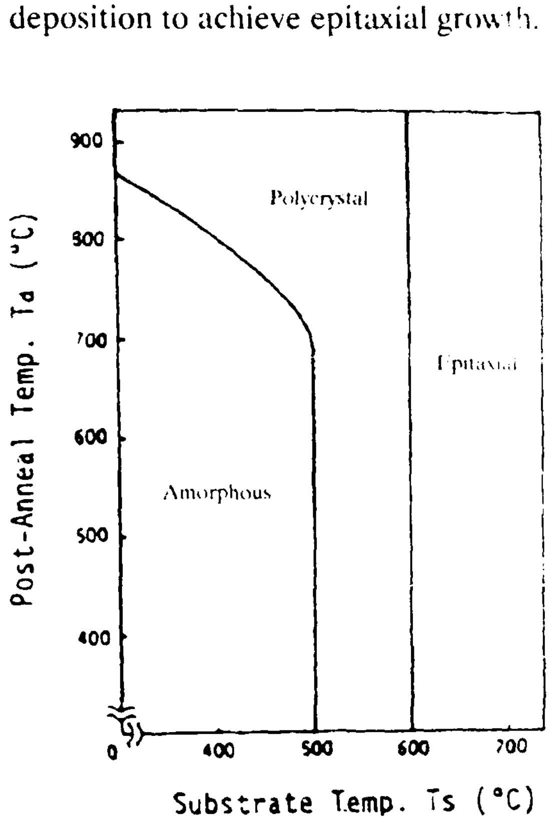


Figure 16. Summary of the results of Sumitomo's annealing studies for the epitaxial growth of $HoBa_2Cu_3O_7$ (from Ref 17). The substrate must be hotter than 600 °C during the deposition to obtain epitaxial growth.

Their best Ho films are epitaxially grown under the conditions described above, followed by a 920-°C anneal in flowing oxygen. X-ray studies confirm the single-crystal nature of the films and SEM observations show less than 50-Å surface roughness. The resistive transition is at 84 K and is 0.4 K wide. The critical current density, J_c, at 77 K is 3.53×10^6 A/cm^2 in zero applied magnetic field and 1.5×10^6 A/cm^2 in a 1.0-tesla field parallel to the c-axis.

These remarkable critical currents were measured by an ac method (Ref 18). Recent ac susceptibility measurements by Malozemoff et al. (Ref 19) show that the behavior of fluxoids in these materials is sensitive to frequency. A magnetic field enhances this sensitivity. Since the critical current is limited by motion of fluxoids in the superconductor, measurements made at a finite frequency in a magnetic field can give anomalous results.

Finally, Sumitomo showed us some preliminary work on other projects. Sputtered films of Y-Ba-Cu-O on MgO have an extraordinary J_c at 77 K of 1.2×10^6 A/cm^2 in an 8-tesla magnetic field. They are sputtering films onto Al_2O_3 that have negligible resistance at 81 K but have low J_cs. Sumitomo is fabricating Josephson junctions and SQUIDS that operate at 4.2 K. Sumitomo is also working on the new thallium- and bismuth-based superconductors. Their preliminary work (as of September 1988) has produced Tl-Ba-Ca-Cu-O films with "R=O" at 124 K and $J_c = 3.2 \times 10^6$ A/cm^2 at 80 K in zero field but which falls off sharply with field. The Bi-Sr-Ca-Cu-O films have "mirror-quality" surfaces, "R=0" at 106 K, and $J_c = 1.7 \times 10^6$ A/cm^2 at 77 K in zero field. There is some significant dropoff of J_c with field but not so severe as with the Tl films.

Contact: K. Higaki, H. **Itozaki**, S. Tanaka; Sumitomo Electric Industries Ltd., Itami R&D Laboratory, 1-1, 1-chome Koyakita, Itami, Hyogo 663, Japan.

Osaka University

Professor T. Kobayashi and his students are building on their experience in conventional superconductor-semiconductor devices (Ref 20-24) to develop devices with high T_c materials. They are tackling difficult materials problems while laying the essential groundwork for fabricating devices of these new materials.

A major thrust of their research is to develop the technology that will be needed for device applications. With this objective in mind they are studying the properties of etchants (Ref 25,26) on polycrystalline "123" films. Their initial results show that 2-micron features can be patterned with phosphoric acid without affecting T_c (Ref 26).

In any application the superconducting element, film or bulk, must be coupled to normal or semiconducting components or leads. High-resistance interfaces introduce local heating and noise, which degrade device performance. To address this problem the Kobayashi group is exploring the use of silver, tin-oxide, and indium-tin-oxide to make low resistance contacts to films.

They are also studying the characterization of films by electron spectroscopy for chemical analysis (ESCA) (Ref 27,28). In ESCA [which is also called x-ray photoemission spectroscopy (XPS)], the film is exposed to x rays and the energies of the emitted secondary electrons, characteristic of the elements, are measured. A depth profile is constructed by making measurements as the film is milled by an argon ion beam.

Oxygen plasma is an efficient way to oxidize these superconductors. Prof. Kobayashi and his students have made detailed studies of the electron cyclotron resonance (ECR) microwave plasma oxidation process in "123" films (Ref 29). ECR ionizes oxygen at low pressures with minimal heating of the plasma. This allows better control of the plasma during processing.

The Kobayashi group's most exciting activity is the epitaxial growth of a multiple heterostructure with "123" layers (Ref 30,31). Films are deposited with an rf magnetron system from off-stoichiometric targets onto (110) $SrTiO_3$ at 670 °C in an argon+40 percent oxygen plasma. First Kobayashi demonstrated that 1,200 Å of either Er "123" or Nd "123" will grow epitaxially on epitaxial Y "123." RHEED measurements show the films have (110) orientation, but there is some slight degradation of the crystal quality, especially with Er. Kobayashi and his energetic students are now growing multiple heterostructures (Figure 17) consisting of alternate Y "123" and Er "123" layers, each 600 Å thick. Epitaxy is retained in successive layers but with some deterioration of crystal quality. The Kobayashi group has also grown 100-, 30-, and 12-Å epitaxial films of Y "123" on (110) and (100) $SrTiO_3$ and on (100) MgO. Crystalline distortion is evident in the accommodation of the 12- and 30-Å films to the $SrTiO_3$ substrate but not for the 100-Å film nor for films of any thickness on MgO. Heterostructures of alternate 12-Å-thick layers of Er "123" and Y "123" have been grown on a (110) $SrTiO_3$ base. RHEED analysis shows some distortion of the crystal. As of June 1988, no transport measurements had been made and the superconducting properties were unknown.

Contact: **Takeshi Kobayashi**; Faculty of Engineering Science, Osaka University, 1-1 Machikaneyama, Toyonaka, Osaka 560, Japan.

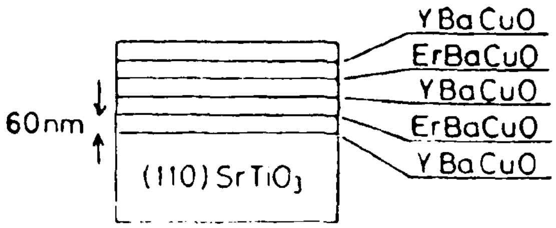


Figure 17. Multiple heterostructure consisting of $YBa_2Cu_3O_7$ and $ErBa_2Cu_3O_7$ layers 600 Å thick on (110) $SrTiO_3$ [from *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988. To be published in 1989. Used with permission of the Materials Research Society (Ref 30)].

Matsushita Electric Industrial Co., Ltd., Osaka

This powerful group, led by Dr. K. Wasa, using rf magnetron sputtering, has grown films of each of the high temperature superconductors (Ref 32-37). We will report only on some of the highlights of their recent work. They have studied the properties of $ErBa_2Cu_3O_x$ films on sapphire as a function of film thickness (Ref 33). The films were grown on R-plane sapphire at 650 °C from a 1:2:4.5 target at a rate of 40 Å/s in a 1:1 Ar/O plasma. Thin films (0.15 and 0.3 micron thick) have semiconductorlike resistance behavior with superconducting onsets at 91 K and very broad transitions. The films improved with increasing thickness, eventually showing metallic behavior and sharper transitions. A 1-micron film had negligible resistance at 80 K and J_c of 2 x 10^4 A/cm^2 at 4.2 K. Migration of atoms of the sapphire substrate into the film is responsible for the poor behavior of the thinner films.

The Matsushita group is sputtering films of the bismuth superconductor (Ref 34-36) from a $Bi_{1.7}SrCa_{1.2}Cu_{1.9}O_x$ target in a plasma with argon/oxygen ratios of from 1:1 to 1:1.5. The best films are grown on (100) MgO substrates at 800 °C, post-annealed in flowing oxygen at 900 °C for 20 minutes, and then held at 865 °C for 5 hours. X-ray diffraction shows only broad peaks corresponding to the 120-K phase with c ≈ 36 Å, oriented perpendicular to the surface. Resistance measurements show the superconducting onset at 115 K and "R=0" at 104 K. Initial critical current measurements yield $J_c \approx 10^6$ A/cm^2 at 90 K in the ambient (Earth) magnetic field.

Wasa and coworkers are also sputtering films of the thallium superconductor from a $Tl_2Ba_2Ca_2Cu_3O_x$ target in a plasma with argon/oxygen = 1:1 onto (100) MgO substrates (Ref 36,37). The substrates are only warmed to 200 °C by the plasma since heating them above 400 °C causes the thallium to reevaporate from the films. These conditions produce films with the composition $Tl_5Ba_{1.5}CaCu_2O_x$. Since thallium has a high vapor pressure at relatively low temperatures, the films are put in a closed alumina crucible and postannealed in flowing oxygen and thallium vapor at 900 °C for 1 minute. The postannealed films' composition is $Tl_{1.54}Ba_{2.5}CaCu_{2.25}O_x$. X-ray diffraction shows sharp peaks corresponding to the "2212" (lower T_c) phase with c ≈ 30 Å and highly oriented perpendicular to the surface. Matsushita researchers also obtain the higher T_c phase with c ≈ 36 Å, but it is unstable. Resistance measurements of the best film, annealed at 900 °C, have the superconducting onset above 115 K and "R=0" at 102 K. The highest J_c in ambient magnetic field is 8.5 x 10^5 A/cm^2 at 4.2 K and 1.2 x 10^5 A/cm^2 at 77 K for a film annealed at 890 °C. It is clear that these films are extremely sensitive to annealing and further work is in progress.

Contact: Kentaro Setsune, **Kiyotaka Wasa**; Matsushita Electric Industrial Co., Ltd., Central Research Laboratories, Moriguchi, Osaka 570, Japan.

CONCLUDING REMARKS

This completes our report on our laboratory visits. The body of work done by these laboratories and by the many other Japanese high T_c laboratories is impressive, especially considering that the field is less than 2 years old. Many advances have been made in laying the foundations of a future superconducting technology.

At frequent symposia Japanese industrial, university, and national laboratory groups share information on their own progress and report on world-wide developments. Interlaboratory work groups attack common problems. Japan is building on its strength in conventional superconductivity. With the advent of high T_c, the "low T_c" budget has been increased. Research groups are enthusiastic, are well equipped, and are strongly backed by management and the Japanese Government. For example, Hitachi, which we did not report on here, spends 10 percent of its sales on research and development (R&D) and product development.* In the course of attacking the many difficult problems that

*Total Hitachi sales in 1987 were $22.5 billion and R&D expenditures totalled $2 billion. Net income was $500 million.

must be solved, Japanese researchers are gaining the "know how" that is going to stand them in good stead in getting to the market with high T_c devices.

ACKNOWLEDGMENT

The authors wish to thank E.F. Skelton for providing x-ray data, H.A. Hoff for microscopy data, and L.H. Allen for critical current density data. They also wish to thank E.F. Skelton, H.A. Hoff, and R.J. Soulen, Jr., for their useful comments on the manuscript. The authors acknowledge the support of the Office of Naval Research (ONR); the Office of Naval Technology (ONT); the Strategic Defense Initiative, Office of Innovative Science and Technology (SDIO/IST); the Defense Advanced Research Project Agency (DARPA); and the Nuclear Defense Agency (NDA).

REFERENCES

1. P.R. Broussard and S.A. Wolf, to be published in J. Crystal Growth.

2. M. Leung, P.R. Broussard, J.H. Claassen, M. Osofsky, and S.A. Wolf, Appl. Phys. Lett. 51, 2046 (1987).

3. H.A. Hoff, A.K. Singh, J.S. Wallace, W.L. Lechter, and C.S. Pande, J. Superconductivity 1, 35 (1988).

4. W.P. Lowe, Ph.D. thesis, Stanford University, W.W. Hanson Laboratories of Physics, 1983, p. 12.

5. B.D. Cullity, *Elements of X-Ray Diffraction* (Addison-Wesley, 1978); M.M. Woolfson, *An Introduction to X-Ray Crystallography* (Cambridge University Press, 1970).

6. M.G. Lagally, *Methods of Experimental Physics* 22 (Academic Press, Inc.), p. 237.

7. M. Prutton, Vacuum 22, 1563 (1972).

8. E.M. Gyorgy, G.S. Grader, D.W. Johnson, Jr., L.C. Feldman, D.W. Murphy, W.W. Rhodes, R.E. Howard, P.M. Mankiewich, and W.J. Skocpol, Appl. Phys. Lett. 52, 328 (1988).

9. A.C. Rose-Innes and E.H. Rhodrick, "Introduction to superconductivity," *International Series in Solid State Physics*, Volume 6 (Pergamon, 1978); G.B. Wright, "A short tutorial on superconductivity," ONRFE Scientific Information Bulletin 13(1), 24-36 (1988); I.K. Schuller, M. Tachiki, and E. Callen, "Dimensional crossover in superconducting superlattices," ONRFE Scientific Information Bulletin 13(3), 1-21 (1988).

10. B.B. Schwartz and S. Foner, "Superconductor applications: SQUIDS and machines," *Nato Advanced Study Institutes Series*, Series B: Physics, Volume 21 (Plenum Press, 1977).

11. T. Van Duzer and C.W. Turner, *Principles of Superconductive Devices and Circuits* (Elsevier North Holland, Inc., 1981).

12. Y. Bando, T. Terashima, and H. Mazaki, *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988 (to be published in 1989).

13. P.M. Mankiewich, J.H. Scofield, W.J. Skocpol, R.E. Howard, A.H. Dayem, and E. Good, Appl. Phys. Lett. **51**, 1753 (1987).

14. T. Takeuchi, Y. Iijima, and K. Inoue, *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988 (to be published in 1989).

15. M. Maeda, Y. Tanaka, M. Fukutomi, and T. Asano, Jpn. J. Appl. Phys. (in press).

16. N. Terada, H. Ihara, M. Jo, M. Hirabayashi, Y. Kimura, K. Matsutani, K. Hirata, E. Ohno, R. Sugise, and F. Kawashima, Jpn. J. Appl. Phys. **27**, L639 (1988).

17. H. Itozaki, S. Tanaka, K. Harada, K. Higaki, N. Fujimori, and S. Yazu, *Proceedings of the Fifth International Workshop on Future Electron Devices-High Temperature Superconducting Devices*, Zao, Japan, 2-4 June 1988.

18. S. Tanaka and H. Itozaki, Jpn. J. Appl. Phys. **27**, L622 (1988).

19. A.P. Malozemoff, T.K. Worthington, Y. Yeshurun, and F. Holtzberg, to be published in Phys. Rev. B (1 September 1988).

20. T. Kobayashi, H. Sakai, Y. Kurita, M. Tonouchi, and M. Okada, Jpn. J. Appl. Phys. **25**, 402 (1986).

21. M. Tonouchi, H. Sakai, and T. Kobayashi, Jpn. J. Appl. Phys. **25**, 705 (1986).

22. H. Sakai, Y. Kurita, M. Tonouchi, and T. Kobayashi, Jpn. J. Appl. Phys. **25**, 835 (1986).

23. M. Tonouchi, H. Sakai, and T. Kobayashi, J. Appl. Phys. **62**, 961 (1987).

24. M. Tonouchi, K. Hashimoto, Y. Sakaguchi, S. Kita, and T. Kobayashi, *Extended Abstracts of the 19th Conference on Solid State Devices and Materials*, Tokyo (1987), p. 171.

25. M. Tonouchi, Y. Sakaguchi, S. Kita, and T. Kobayashi, Jpn. J. Appl. Phys. **27**, L98 (1988).

26. Y. Yoshizako, M. Tonouchi, and T. Kobayashi, Jpn. J. Appl. Phys. **26**, L1533 (1987).

27. M. Tonouchi and T. Kobayashi, *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988 (to be published in 1989).

28. M. Tonouchi, Y. Yoshizako, T. Takahashi, Y. Sakaguchi, S. Kita, Y. Fujiwara, and T. Kobayashi, Jpn. J. Appl. Phys. **26**, L1462 (1978).

29. S. Minomo, M. Taniguchi, Y. Ishida, M. Sugiyo, T. Takahashi, M. Tonouchi, S. Kita, and T. Kobayashi, Jpn. J. Appl. Phys. **27**, L411 (1988).

30. M. Tonouchi, Y. Yoshizako, M. Iyori, and T. Kobayashi, *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988 (to be published in 1989).

31. M. Tonouchi, Y. Yoshizako, M. Iyori, and T. Kobayashi, *Proceedings of the Fifth International Workshop on Future Electron Devices-High Temperature Superconducting Devices*, Zao, Japan, 2-4 June 1988.

32. H. Adachi, K. Setsune, and K. Wasa, Phys. Rev. **B35**, 8824 (1987).

33. K. Hirochi, H. Adachi, K. Setsune, O. Yamazaki, and K. Wasa, Jpn. J. Appl. Phys. **26**, L1837 (1987).

34. H. Adachi, Y. Ichikawa, K. Setsune, S. Hatta, K. Hirochi, and K. Wasa, Jpn. J. Appl. Phys. **27**, L643 (1988).

35. Y. Ichikawa, H. Adachi, K. Hirochi, K. Setsune, and K. Wasa, *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988 (to be published in 1989).

36. K. Wasa, H. Adachi, Y. Ichikawa, K. Setsune, and K. Hirochi, *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988 (to be published in 1989).

37. Y. Ichikawa, H. Adachi, K. Setsune, S. Hatta, K. Hirochi, and K. Wasa, submitted to Appl. Phys. Lett.

Michael S. Osofsky received a B.S. in physics in 1979 from the Massachusetts Institute of Technology and a M.S. and Ph.D. in physics in 1981 and 1987 from the University of Illinois, Urbana. From 1981 to 1986 Dr. Osofsky conducted research at the University of Illinois in amorphous materials near the metal-insulator transition. Since October 1986 he has been working in high temperature superconductivity at the Naval Research Laboratory. Dr. Osofsky's technical experience includes thin film vacuum evaporation, cryogenic techniques, x-ray diffraction, design and construction of electron optical components, and operation of VTS SQUID susceptometer. Within the past year or two he as written or coauthored more than a dozen publications on high T_c superconductors.

Phillip R. Broussard graduated Summa Cum Laude from Louisiana State University and received his Ph.D. in applied physics at Stanford University under Prof. T.H. Geballe. A National Research Council postdoctoral fellow at the Naval Research Laboratory, Dr. Broussard is the author of 10 papers on sputtered niobium, zirconium, and tantalum multilayers and on high T_c films.

Earl Callen is a member of the staff of the Office of Naval Research Far East. He is a Professor Emeritus of The American University. He received his Ph.D. under John Slater at MIT and has been active in the physics of magnetoelastic phenomena and amorphous magnetism. In the first cycle of his life he was much involved in physics and public affairs.

RESEARCH INSTITUTE FOR METAL SURFACE OF HIGH PERFORMANCE (RIMES):
An Example of Japanese Transfer of Technology Techniques

Fred Pettit

RIMES is a research and development (R&D) company that illustrates a strategy followed to establish new and advanced technologies in Japanese industry. An R&D target having potential for exploitation is identified by using the input from industry, academia, and government. The targeted technology is developed or advanced in certain companies through the formation of a transitory R&D venture involving the direct participation of employees from these companies. Governmental leadership coupled with the enthusiastic participation of industry and academia are important characteristics of this technology transfer process.

RIMES is an acronym for Research Institute for Metal Surface of High Performance. It is a special research and development (R&D) company composed of researchers from different companies with a common interest. That interest is coatings, especially SiC coatings, deposited on materials by using chemical vapor deposition techniques. The companies in RIMES may be competitors in regards to their products, and they only share the technical data generated at RIMES. RIMES has been in existence for 2 years, and it will exist for a period of 6 years. After that time supposedly enough progress will have been made to permit each company to use the new technology generated in ways most effective for its own specific products.

RIMES has 17 company members (see membership list of Japan Research and Development Center for Metals), mainly steel and nonferrous metal producers. Each company is encouraged to provide researchers to work at RIMES. Moreover, RIMES is located at the facilities of one of the participating companies. The building for RIMES is isolated from the rest of this company's facilities and the researchers from the other companies do not have free access to the host company's facilities other than RIMES' building. Each month the researchers at RIMES have discussions of their recent results with representatives of the participating companies present. Moreover, the individual researchers have more frequent meetings with technical representatives from their parent company. Written reports are prepared at prescribed time intervals and are available to the members of RIMES. Researchers are assigned to RIMES by their parent company for a period of 2 years. At the end of that period they may be appointed for another 2-year term or go back to their parent company. One of the objectives of RIMES is to develop coatings expertise back in the individual companies, so one researcher will usually not stay at RIMES for the full 6-year period.

Since RIMES is concerned with advancing and transferring the technology of chemical vapor deposition (CVD), three types of CVD are being investigated: thermal CVD, plasma-assisted CVD, and metal-organic CVD. These techniques are being used to form SiC coatings on various alloys. After 2 years of effort equipment has been installed and is now operational to deposit coatings by each of these techniques. Each apparatus is in a separate room in the RIMES building and is the responsibility of a researcher from one of the participating companies. RIMES has the equipment to deposit coatings and measure coating thicknesses, but facilities are not available for in-depth characterization of the coatings by techniques such as scanning electron microscopy or transmission electron microscopy. Each researcher attempts to characterize the coatings by using the facilities of his own company. If one company does not have a certain piece of equipment to perform a required analysis or examination, but another company does, the researcher from the company that has the equipment may perform the necessary work. It is unusual for the other researcher to accompany him. In fact, such interactions where researchers from one company examine specimens prepared by researchers from another company seem to be rather few.

The work performed at RIMES is concerned with defining procedures to fabricate, reproducibly, coatings with specific properties. The mechanisms by which the coatings are formed receive less emphasis; however, the approach is far from totally empirical. For example, the deposition of SiC coatings on alloys at elevated temperatures is affected by silicide and carbide formation in the alloys. The RIMES research examines the various possible reactions using thermodynamic considerations to attempt to determine the conditions that will produce the most desirable coatings. The researchers are young, conscientious, and enthusiastic, with masters degrees or the equivalent in experience. They have been employed by their companies for at least about 5 years.

RIMES is an effective technology advancement and transfer organization. It permits companies to pool resources in advancing technologies in which there is a common need. How was it formed? How and why was the CVD deposition of SiC chosen as an important technology? How is it supported? To answer these questions another organization must be considered--the Japan Research and Development Center for Metals (JRCM).

JRCM is a foundation in the Agency of Industrial Science and Technology, which in turn is part of the Ministry of International Trade and Industry (MITI). JRCM was established in October 1985. Its function is to support technological advancement in the metals-related area by helping to overcome obstacles such as foreseeing industrial needs, increased risks in commercialization of new materials, and inefficient technology transfer. Financial support for JRCM comes from MITI as well as from its 58 supporting members, which are as follows:

Nippon Steel Corp.*
NKK Corp.*
Kawasaki Steel Corp.*
Sumitomo Metal Industries, Ltd.*
Kobe Steel, Ltd.*
Nisshin Steel Co., Ltd.*
Nakayama Steel Works, Ltd.
Godo Steel, Ltd.
Aichi Steel Works, Ltd.
Sanyo Special Steel Co., Ltd.
Daido Steel Co., Ltd.*
Topy Industries, Ltd.
Nippon Koshuha Steel Co., Ltd.
Hitachi Metals, Ltd.
The Japan Steel Works, Ltd.*
Mitsubishi Steel Manufacturing Co., Ltd.
Nippon Metal Industry Co., Ltd.
Nippon Stainless Steel Co., Ltd.
Nippon Yakin Kogyo Co., Ltd.*
Kanto Special Steel Works, Ltd.*
Kubota, Ltd.
Pacific Metals Co., Ltd.
Yodogawa Steel Works, Ltd.
Showa Denko K.K.
Japan Metals & Chemicals Co., Ltd.
Nippon Denko Co., Ltd.
Nippon Mining Co., Ltd.*
Mitsubishi Metal Corp.*
Mitsui Mining & Smelting Co., Ltd.
Sumitomo Metal Mining Co., Ltd.*
Nippon Light Metal Co., Ltd.
Sumitomo Light Metal Industries, Ltd.
Showa Aluminum Corp.
Mitsubishi Aluminum Co., Ltd.
Sky Aluminum Co., Ltd.
The Furukawa Electric Co., Ltd.*
Sumitomo Electric Industries, Ltd.
Fujikura Ltd.*
Hitachi Cable, Ltd.*
Showa Electric Wire & Cable Co., Ltd.
Mitsubishi Cable Industries, Ltd.
Vacuum Metallurgical Co., Ltd.
The Industrial Bank of Japan, Ltd.
The Dai-ichi Kangyo Bank, Ltd.
The Fuji Bank, Ltd.
The Sanwa Bank, Ltd.
The Sumitomo Bank, Ltd.
The Taiyo Kobe Bank, Ltd.
Ishikawajima-Harima Heavy Industries Co., Ltd.*
Toshiba Corp.
NEC Corp.
Hitachi, Ltd.
Mitsubishi Heavy Industries, Ltd.
Nissan Motor Co., Ltd.
Toyota Motor Corp.
Kawasaki Heavy Industries, Ltd.
Mitsubishi Electric Corp.
Nippon Telegraph and Telephone Corp.

JRCM attempts to perform its function by emphasizing three "I"s:

- **Integration** of User Needs and Maker Seeds
- **Identification** of R&D Targets
- **Implementation** of Efficient R&D

The first "I," Integration of User Needs and Maker Seeds, involves the free exchange of information and opinions between metals producers and users. This is accomplished by a variety of techniques that include salons or conversation rooms to discuss specific topics such as electronic materials, superconductivity, biotechnology, aerospace, and ultrafine particles. Experts from government, universities, and industry are often invited to present lectures and to help initiate discussions on specific topics. The object is to obtain a variety of views on different subjects by providing different forums for expression and interaction.

The second "I," Identification of R&D Targets, is the responsibility of JRCM's Research Committee, whose members include employees of JRCM, university faculty, and employees of the member companies. This committee is constantly seeking to define new search and survey themes as they become evident

*Also a member of RIMES.

through the "integration of user needs and maker seeds" process. The purpose of the search and survey is to examine in detail certain topics to determine whether an important R&D target can be identified. Priority is given to the following:

- Projects that are difficult for a single company to undertake independently.
- Projects ranging over wide areas of technology.
- Projects that require highly specialized scientific and technological knowledge.
- Projects that are high risk.
- Projects in which the available technology is insufficient and a combined effort on the part of metals users and producers is essential.

Searches and surveys were begun in 1988 to determine the state-of-the-art and science of. (1) properties of materials and material processing technologies under extreme conditions such as super-high vacuum, super-high pressure, super-high magnetic field strength, super-high temperature, super-low gravity, and super-high rate of forming; (2) intermetallic compounds; and (3) single crystals.

The third "I," Implementation, occurs once the target has been set by the Research Committee. It can consist of an R&D project or a feasibility study. In either case such efforts are usually supervised by a senior researcher and piloted by a technical committee in JRCM. Tubular goods for severe environments encountered in oil production, materials for molten carbonate fuel cells, and new materials for improved reliability of light water reactor facilities are examples of R&D projects currently being pursued by JRCM. Some typical feasibility studies have been concerned with: (1) aluminum-lithium alloys for aerospace applications, (2) rapidly solidified aluminum plate, and (3) semisolid forming processes.

When appropriate the results from the R&D projects or the feasibility studies are used to establish joint ventures between companies with mutual interests in the new technology. While the development of such joint ventures is the primary objective of JRCM, it is not directly involved with the new venture. An R&D company is formed composed of the participating companies. The capital for this R&D company is provided by the participating companies and, if necessary, up to 70 percent of the capitalization can be obtained from the Japan Key Technology Center (Japan Key-TEC), whose function is to promote private sector research and development of fundamental technologies seen as providing an important impetus of progress toward the 21st century society. Japan Key-TEC is part of the Ministry of International Trade and Industries and the Ministry of Posts and Telecommunications. Since its inception JRCM has established two R&D companies. One is RHEOTECH (rheotechnology), which is concerned with the development of the semisolid forming process for metallic materials. The other is RIMES. In the September 13, 1988 issue of the Japan Industrial Journal it was announced that seven aluminum manufacturers were to form an R&D company, "Alithium," for the development of aluminum-lithium alloy production technologies. This project will include: (1) research on the properties, alloy design technology, and secondary and

tertiary processing conditions necessary for economical production of good high-strength alloys; (2) establishment of new melting/casting technologies for the production of safe, high-quality alloys that include development of methods for reducing hydrogen gas absorption and development of refractory materials and coolants that do not react with lithium; and (3) establishment of a scrap recycling process for enhanced cost performance. It is apparent that a third R&D company will form because of JRCM's efforts.

R&D company combined ventures evolving from a network of governmental organizations designed to incorporate the knowledge and experience of industry and academia are not the exception but the rule in Japan. Government plays a key role in that it not only brings the players together but it expertly stimulates their interaction and adroitly identifies the key targets. The university and industrial participants accept the governmental role especially during the initial stages of this process. The participation of government decreases as the R&D company is formed, with the industrial participants becoming the dominant participants.

F.S. Pettit is a liaison scientist with ONR Far East. Professor Pettit is on sabbatical from the Materials Science and Engineering Department at the University of Pittsburgh. Dr. Pettit's professional interests are in high-temperature materials and surface stability and the use of coatings for protection.

RESEARCH AND APPLICATIONS OF METALLIC SUPERLATTICES, HIGH T_c SUPERCONDUCTORS, X-RAY OPTICS, AND COMPACT SYNCHROTRONS

Charles M. Falco

This article describes research on metallic superlattices, high T_c superconductors, and x-ray optics and also reports on the development of compact synchrotrons for generation of soft-x-rays. This information was obtained at the Materials Research Society International Meeting on Advanced Materials in Tokyo and from the Japan Research and Development Center for Metals (JRCM), Canon's Central Research Laboratory, NEC Corporation, the Materials Science Department at the University of Tokyo, and Sumitomo Heavy Industries.

INTRODUCTION

During a visit to Japan in May/June 1988 to speak at the Materials Research Society (MRS) International Meeting on Advanced Materials, I visited several laboratories conducting research on metallic superlattices, high T_c superconductors, and x-ray optics and one company that is developing a "compact" synchrotron, with a number of scientific and technological applications. This article describes information obtained during these visits.

MRS INTERNATIONAL MEETING ON ADVANCED MATERIALS

Background

This meeting consisted of 21 symposia; I attended the multilayer and superconductivity symposia. I presented one of the plenary lectures in the multilayer symposium, on metallic superlattices, and chaired the session on superconductivity and transport phenomena. Because of the concurrent symposium on superconductivity that was mostly high T_c, the superconductivity work reported in the multilayer symposium was mostly low T_c.

Multilayer Symposium

The organizers of the multilayer symposium told me they had contacted every Japanese group working on metallic superlattices and that almost all of them had contributed papers. The multilayer symposium was the largest at the conference, running for four and a half days. Thus, this meeting was a good opportunity to gauge the extent of Japanese involvement in

metallic superlattices. Japanese involvement is surprisingly large and doesn't seem to have "suffered" people moving out of it into high T_c superconductivity, as has been the case in the United States.

Judging from the addresses on the abstracts for this symposium, there are about 23 Japanese universities working on metallic multilayers and superlattices, some with more than one group. For example, Tohoku University lists five separate groups with different affiliations: Physics, Applied Physics, Electrical Engineering, Engineering Science, and Institute for Materials Research. After trying to eliminate double counting (e.g., making sure addresses such as "Engineering Science" and "Electrical Engineering" aren't the same group), I estimate that there are about 30 separate Japanese university groups currently working on metallic multilayers and superlattices. In quantity, this is a significantly larger effort than currently underway in the United States. The abstracts revealed that there are more than 17 Japanese companies working in this area and 5 national laboratories or facilities. Again, this is a much larger number than at U.S. companies and national labs.

Research on metallic multilayers and superlattices has been following an exponential growth curve for almost 20 years, with a doubling time of 3 years. Judging by the number of papers contributed to this meeting, I expect this exponential growth will continue, although with an increasingly large proportion of the research being conducted by the Japanese.

Superconductivity Symposium

The general atmosphere at this symposium was strikingly low key, as compared to comparable sessions held at the MRS meeting in Boston 6 months earlier and the American Physical Society meeting in New Orleans 2 months previously. It is difficult to tell whether some of the adrenaline is leaving the field or whether the Japanese just have a more businesslike attitude toward research. For example, when one of the "heroes" of this field, Professor S. Tanaka of the University of Tokyo, gave his invited talk on the "Future of High Temperature Superconductivity," the room, which held about 400 chairs, was only about two-thirds full.

The list of Japanese companies reporting results on high temperature superconductivity at this conference reads like a "Who's Who" of electronics and computers: Fujitsu, Furukawa Electric, Hitachi (both the Electric and the Cable divisions), Matsushita, Mitsubishi Electric, Sumitomo Electric, NEC, NTT, Sanyo, Sharp, and Toshiba. Some companies, such as Nippon Steel and Kobe Steel, represent industries that one does not normally associate with superconductivity research. There was also a mixture of papers from other companies: Chichibu Cement Company, Wako Pure Chemicals, Asahi Glass, Mitsui Mining & Smelting, Showa Denko, Ube Industries, Tokuyama Soda Company, Onoda Cement Company, Fujikura.

The above lists definitely underestimate Japanese industrial involvement in superconductivity, since some companies such as Sumitomo are actually made up of a number of independent companies: Sumitomo Electric, Sumitomo Chemicals, Sumitomo Heavy Industries, etc. It isn't always possible to distinguish between them from the addresses on the abstracts. Also, other companies that I know have superconductivity programs, such as Nishin Steel, NKK Steel, and Canon, did not have papers at the MRS meeting.

Although I have concentrated this discussion on the involvement of Japanese companies in superconductivity research, there also were many universities represented (just as in the United States).

JAPAN RESEARCH AND DEVELOPMENT CENTER FOR METALS (JRCM)

I was invited by the Japan Research and Development Center for Metals to present a seminar on metallic superlattices. The JRCM is a group of 31 member companies from the steel and nonferrous metal industries. It was established in October 1985 to help clarify the user needs for materials used under severe conditions, to help minimize the risk in development for commercialization of new materials, and to help exchange information on research and development. Japan may lose their steel industry to Korea by the end of the next decade, and this group is to help them find new areas of manufacturing.

For my seminar the JRCM rented a hall in the center of Tokyo to make it easier for representatives of the member companies to attend. There were about 100 people in attendance. Lunch and a reception were held before my talk and dinner afterwards. This gave me considerable opportunity for discussion with various people. I learned that NKK Steel, which is the fourth largest steel company in the world, has about 15 people working on high T_c superconductors. Nishin Steel also has about the same number. Also, Nishin Steel just bought a completely equipped molecular beam epitaxy (MBE) system from Vacuum Generators Corporation of Great Britain, with Auger, XPS, SIMS, etc. The cost of this system is about $2 million. Two young researchers from this company who were responsible for the MBE system said that the company bought it with the hope that something interesting and useful would be discovered with it. That is, there was no specific, well-defined development in mind requiring this equipment. I found this corporate attitude extremely interesting and, as far as I could tell, fairly representative.

CANON CENTRAL RESEARCH LABORATORY

Canon is a major supplier of optical photolithography equipment for the semiconductor industry and also has a significant electronics development effort for its own products. Because of this I was invited to Canon's Central Research Laboratory in Atsugi to present a seminar on my x-ray

optics and high T_c superconductivity research. Atsugi is located about 50 km southwest of Tokyo. Canon's Central Research Laboratory is in a very new building, adjacent to NTT's new laboratory. Several other large companies have research facilities in Atsugi as well.

At this laboratory Canon has 15 people working on superconductivity and about 15 people working on x-ray optics. I was able to talk with their x-ray optics group during my visit and discussed some of the group's plans for the future.

My host at Canon told me there were about 300 workers in the central lab. We only had a short time scheduled for laboratory visits, so I was not able to see the full extent of Canon's facilities. We visited a central analytical laboratory with a number of instruments (TEMs, surface analysis, etc.) and also saw an MBE apparatus that recently had been converted from gallium arsenide to silicon and now is being used for x-ray optics. My general impression from this brief tour is that Canon's research lab certainly has the necessary facilities to conduct its research.

Canon will have a first-generation, grazing incidence x-ray lithography exposure system ready for delivery with the first of the compact synchrotrons being developed by several Japanese companies (see the description of my visit to Sumitomo Heavy Industries). Canon is testing some of these components now at the Photon Factory in Tsukuba. It is interesting to note that beam time at the Tsukuba synchrotron costs private companies ¥50,000/h (about $385). Canon is actively conducting research aimed at a second-generation system based on multilayer coatings. Nikon has a similar size x-ray optics effort, although Canon doesn't know what fraction of Nikon's effort is devoted to multilayers.

If past experience is repeated, these early generation x-ray lithography instruments will be in the hands of Japanese manufacturers several years before production versions are offered for sale elsewhere. This will give them a head start of several years on non-Japanese companies, unless the United States takes a more active role. Already Japan has six of the world's ten largest manufacturers of semiconductors, including the top three.

Unfortunately, there was no time to learn about Canon's superconductivity work during this visit. When I asked why a camera company had a superconductivity program, I was told that "no Japanese electronics manufacturer can afford not to have an active research program in this field."

NEC CORPORATION

There are 1,200 workers at the lab I visited, which is 11 years old. It is located about 20 km southwest of the center of Tokyo, in Kawasaki. Mr. Jun-Ichi Fujita of NEC had visited my laboratory to discuss our superconducting thin films work a few months previously, following the MRS Spring Meeting in Reno.

I was shown an electron beam gun system used for producing high T_c superconductors. NEC is using BiO_2, a SrCa alloy, and pure Cu sources. A homemade plasma machine in the same lab is used to melt the SrCa alloy for producing charges for the guns. A ring on the inside of this apparatus has been designed to blow pure molecular oxygen onto the substrate during growth.

Mr. Fujita estimated that there are about four workers at NEC working on high T_c films, six on low T_c films, five on bulk materials, three growing single crystals, and an indeterminate number on analysis. He estimated the total working in this field to be about 30 or 40.

Next I was shown a five-chamber MBE apparatus that was built by Dr. Atsushi Kamijo, who left for the United States shortly after my visit to work for a year at Illinois in Peter Flynn's lab. The first chamber was a turbo-pumped introduction chamber. The second was a large (about 18-inch diameter) ion-pumped cleaning chamber that could heat samples to 800 °C at 10^{-9} Torr. The third was a growth chamber that operated at 3×10^{-10} Torr with liquid nitrogen and had two 6-kW, 20-cc electron beam guns with quartz crystal monitors run by an Inficon IC 6000. The analysis chamber contained an Auger spectrometer with sputter ion milling. The analysis chamber system was designed with an extra introduction chamber to allow Auger analysis of other samples such as sputtered high T_c superconductors, bypassing the other parts of the system. That way the samples could be analyzed without contamination of other chambers.

Dr. Jaw-Shen Tsai, who received his degree from Stony Brook in the late 1970s, is working on Y-Ba-Cu-O junctions. He developed a technique to crack the substrates and then push an oxidized bulk piece of Pb up against them to make tunnel junctions at the freshly exposed edge. He said the same technique does not work well with bismuth materials because the films are not well oriented. NEC continues to have about six people working on the niobium Josephson junction computer because of a long-term commitment to the Ministry of International Trade and Industry (MITI). There are three companies (Fujitsu, Hitachi, and NEC) that have a joint MITI-funded effort, each with about six or seven people.

This NEC research laboratory has 10 to 12 MBE machines for GaAs and is currently the world's largest semiconductor producer. NEC also sells a clever Young's modulus tester and an elastic constant tester designed for thin films.

PROFESSOR YAMAMOTO'S LABORATORY AT THE UNIVERSITY OF TOKYO

Professor Yamamoto was one of the organizers of the multilayer symposium at the MRS meeting and was the one who invited me to speak there. Other Japanese researchers spoke highly of Professor Yamamoto and his research program. Professor Yamamoto has four laboratory rooms located at different places within the building housing the Materials Science Department. Walking between the rooms gave me the opportunity to see other labs in addition to his. The building itself is 60 years old, built immediately after the great Tokyo earthquake. The contrast between laboratories in Japanese companies and in universities is striking. It is clear from this trip, and from visits I made last summer, that most Japanese research and development (R&D) money goes into the "D" at companies and a much smaller portion into the "R" at universities. The first laboratory I visited had two Langmuir-Blodgett tanks for producing monolayer

organic films. The tanks themselves were enclosed in separate plastic "rooms within rooms," each of which occupied maybe one-quarter of the total lab area. The second laboratory was air conditioned. It contained two sputtering machines for producing metallic superlattices. One, the older original machine, had a single cathode with twin targets on it. These targets were stationary; the substrates rotated above the targets, separated by a wall or baffle in order to produce multilayers. The second system was newer and diffusion pumped with two separate targets. Professor Yamamoto's MBE apparatus, located in a basement laboratory, was built by Eiko, which is now exporting later versions of this machine to the United States. It has separate introduction and growth chambers. The growth chamber has both a turbo and a diffusion pump and reaches the mid 10^{-10} Torr range. The apparatus has two electron guns for deposition and reflected high energy electron diffraction (RHEED) for monitoring film growth. At present there is no other analytical equipment on this system (e.g., Auger or XPS). In a room adjacent to Yamamoto's MBE lab is a positron annihilation experiment. The final lab I visited had a small diffusion-pumped, ion beam sputtering system that is being rebuilt to produce high T_c films.

SUMITOMO HEAVY INDUSTRIES

At the last moment I arranged to visit the Sumitomo Heavy Metals facility in Tanashi City to view the compact, superconducting synchrotron called "Aurora" that Sumitomo is developing. Tanashi City is located about 15 minutes by express train northwest of the Ikebukuro train station in Tokyo. This was a very valuable visit as it gave me an advance view of one of these synchrotrons, which will find their way to many laboratories over the next decade.

I was told that I was the first "outsider" allowed to visit Sumitomo's prototype synchrotron. The synchrotron in size very much resembles SURF-II at the National Bureau of Standards in Gaithersburg. The synchrotron is in final assembly now, with the first synchrotron light expected by the end of this year. If Sumitomo succeeds, the first machine should be ready for sale within 2 years after that.

The synchrotron is remarkably small, although it does weigh 20 metric tons. Although I wasn't permitted to take photographs, the artist's drawing that has appeared in several advertisements is an accurate representation of the size of the synchrotron. Because it is encased in iron to provide the correct magnetic field profile from the superconducting magnets, not much additional radiation shielding is required. Concrete walls approximately 1 foot thick are sufficient, so construction costs should be small. "Assuming there are no unexpected development problems" it will cost about $15 million (plus about $500,000 for each beamline) and should be ready for delivery in 2 years. The steady state total power required is only 250 kW.

A big market is projected for such systems, for x-ray lithography, biomedical imaging, and materials analysis. This is consistent with what I was told by the manager of the x-ray optics program at Canon. He said that NTT is presently installing a synchrotron made by Toshiba for lithography. NTT's machine is scheduled to be functional before the summer of

1989. A recent article in *Synchrotron Radiation News* estimates about 175 of such synchrotrons will be needed within the next 10 years to supply the demand for x-ray lithography alone.

GENERAL NOTES

I found industrial people everywhere to be very concerned about the trade issue and by the U.S. criticism that too much of Japanese R&D money goes into development rather than research. This was a standard topic for conversation, with the discussion always being initiated by the Japanese. Several steel company executives said they agree with this objection and feel Japan is already starting to rectify the problem.

I was told by one research manager that attitudes on many things are rapidly changing. In the past someone would be viewed very badly if he changed companies or went from a university to a company or *vice versa*. This person estimated that maybe fewer than 1 percent of the people ever did this in the past. However, he said this policy is rapidly changing and such things are now possible and, in some cases, encouraged.

Charles M. Falco received his Ph.D. degree in physics from the University of California at Irvine in 1974. He spent the next 8 years in the Solid State Science Division at Argonne National Laboratory, where he was group leader of the Superconductivity and Novel Materials Group. In 1982 he joined the University of Arizona as a full professor, with joint appointments in the Physics Department, the Optical Sciences Center, and the Arizona Research Laboratories. His research in recent years has concentrated on studies of various physical properties of artificial metallic superlattices. Of primary interest have been superconductivity, magnetism, magneto-optical properties, elastic constants, and nucleation and growth of these materials by sputtering and molecular beam epitaxy. In 1986, with funding from the University Research Initiative Program sponsored by the Air Force Office of Scientific Research, he established the Laboratory for X-Ray Optics to fabricate and study metallic multilayers for use in the soft-x-ray region. Dr. Falco has published over 100 scientific articles to date. He is a fellow of the American Physical Society and a senior member of the IEEE.

KUROSHIO EXPLOITATION AND UTILIZATION RESEARCH (KER)

Wayne V. Burt

The Kuroshio Exploitation and Utilization Research (KER) project was established in 1977 to clarify the mechanisms of the variation in the Kuroshio Current, to understand the characteristics of the Kuroshio and adjacent waters, and to estimate the possibilities to further exploit the resources and capabilities of the Kuroshio. This article discusses the various KER research projects initiated to fulfill these objectives.

INTRODUCTION

Kuroshio Exploitation and Utilization Research (KER), a major multi-organizational research project, was established in Japan in 1977 to study the Kuroshio Current and surrounding waters in great detail. Originally the plan was to carry out the study for a period of 10 years. The agencies involved in KER include the Japanese Science and Technology Agency, regional laboratories of the Japanese Fisheries Agency, the Hydrographic Department of the Maritime Safety Agency, the Marine Department of the Japanese Meteorological Agency (JMA) and JMA's coastal marine observatories, Tokai University's Faculty of Marine Science and Technology, and the Japanese Marine Science and Technology Center. The Japanese Science and Technology Agency is the principal source of funding for KER.

The objectives of the KER program are to clarify the mechanisms of the variation in the Kuroshio Current, to understand the characteristics of the Kuroshio and adjacent waters, and to estimate the possibilities to further exploit the resources and capabilities of the Kuroshio. The following projects were initiated to fulfill these objectives:

- Kuroshio Fluctuation Project, to clarify the mechanism of the variation in the Kuroshio.
- Self-Purification Project, to clarify the role of the Kuroshio in the purification process of the coastal environment.
- Biological Productivity Project, to clarify the relationship between the fluctuation of the Kuroshio and the organic production in the Kuroshio and its surrounding area.
- Kuroshio Energy Project, to explore the possibility of harnessing the Kuroshio power.

In 1986 two additional projects were added to the KER program:

- Air-Sea Interaction Project
- Effect of the Kuroshio on Weather Project

In 1986 scientists from the People's Republic of China began to participate in the KER research program. In July 1988, a Japanese oceanographer from the University of Tokyo informed me that a formal agreement between the two countries was about to be signed. The expanded area that is to be studied by the two nations under the agreement includes most of the East China Sea except for the Korean exclusive economic zone to the south and west of Korea and the Taiwanese exclusive economic zone to the north and east of Taiwan.

Annual data reports and oceanographic atlases have been published based on data collected in KER. In addition, a publication list of "KER Annual Contributions" contains the titles of several hundred papers. Unfortunately, for marine scientists in other countries, the papers are in Japanese.

KUROSHIO FLUCTUATION PROJECT

This is the key project of KER. First, the fluctuations on a number of time and space scales are determined, ranging from tidal to interannual and from a few tens of meters to several thousand kilometers. Then the physical mechanisms causing these fluctuations are determined. Finally, models are constructed to allow predictions of variations on various time and space scales. The fluctuations have been studied for over 50 years and a good deal of information has been obtained, especially about the large-scale interannual variations of the meanders in the Kuroshio Current just south of Japan. The Kuroshio is unique in the world's ocean current systems in that part of the time it has one large quasi-stationary meander located in the area south of the coast of Honshu, the main island of Japan. When the large quasi-stationary meander is missing, much smaller nonstationary eddies form and move, one at a time, across the same area of the ocean just south of Honshu.

When a large quasi-stationary meander develops, it last from 2 to 10 years. This meander loops to the south off the southeastern coast of Honshu. Its diameter is about 250 kilometers and its center is near 31° N. latitude and 135° E. longitude. This large quasi-stationary meander occurred and disappeared three times between World War II and 1980. There is no generally accepted theory as to what causes this meander to develop and then disappear several years later.

The cycle of nonstationary meanders starts with nearly straight flow along the south coast of Honshu. Next a small- to medium-scale meander forms centered near 138° E. longitude. This meander moves to the east or northeast with a speed of about 8 km/day. This cycle of formation and movement downstream of nonstationary meanders repeats itself two to three times a year until the time that the next quasi-stationary meander develops.

Besides the large-scale variations in transport and water temperature associated with the meanders in the Kuroshio, there are changes in total transport by the current on time scales ranging from tidal to interannual.

SELF-PURIFICATION PROJECT

A large share of the heavy industry and population in Japan is concentrated along the southern coast of Honshu and around the Inland Sea to the southwest of Honshu. This concentration adds considerable amounts of anthropogenic materials to the coastal waters south of Japan. The coastal environment is a very complex system that is controlled by a wide variety of physical, chemical, and biological processes.

Much of this anthropogenic material is swept away by the Kuroshio. However, the efficiency of the Kuroshio in flushing away near-coastal pollutants depends upon the meander mode that it is in at any particular time. When the meander is large and quasi-stationary, pollutants tend to be trapped in the colder waters north of the boundary between the northern edge of the Kuroshio and the coast; the flushing away of the pollutants by the Kuroshio is much less efficient than it is during the periods when the smaller nonstationary meanders are moving through the area.

Observations are made from the coast out through the Kuroshio to determine the time and spacial distributions of about a dozen organic and inorganic constituents of the anthropogenic materials including some heavy metals. This accumulation of data is providing useful information on the vicissitudes of pollutants in the marine environment south of Japan.

BIOLOGICAL PRODUCTIVITY PROJECT

The oceanic area between the Kuroshio Current and the south coast of Japan is the spawning ground and nursery for a number of commercially important species of pelagic fishes. The time and space changes in the position and strength of the Kuroshio have marked effects on the efficiency of the spawning and nursery grounds. Eggs and larvae are moved by the currents and their survival depends upon the abundance of food, what is preying on them, and when they are carried downstream by the Kuroshio out of the spawning area. For example, the plankton that the growing sardine depends upon for food tends to decrease whenever the large quasi-stationary meander is present. This lessening of the food supply affects the production of sardines in the area south of Honshu. In addition, the aggregate spawning of several species of fish is less than normal when the Kuroshio meanders widely. Production of eggs is high when meandering disappears and the Kuroshio Current takes a path almost parallel to the southern coast of Honshu.

The research in the project consists largely of repeated samplings of the biota at all seasons of the year on lines running seaward from the northeast, south, and southwest coasts of Japan with a concentration of lines along the southern coast. The primary interest is in fish eggs, fish larvae, and feed plankton for the juvenile fish and the relationships between their abundance and fluctuations in oceanographic conditions related to shifts in the position of the Kuroshio Current.

KUROSHIO ENERGY PROJECT

The Japanese believe that it will be possible to extract large amounts of usable power from the Kuroshio Current sometime in the future. The principal objectives of their present study are twofold: (1) to

develop technology for the long-term measurement of the power in the Kuroshio and (2) to analyze the time and space distribution of power with numerical models. Based on presently available data, a series of numerical experiments has been carried out to simulate the Kuroshio and to endeavor to assess the environmental impact that extracting power from the Kuroshio might bring about.

Current meter arrays have been anchored in three locations in the Kuroshio Current to obtain data on the variability of the current. One was placed near Iromote Island, the southernmost island in the Ryukyu chain of islands southeast of Japan, on the eastern edge of the Kuroshio Current. A second array was placed in the Tokara Strait where the bulk of the Kuroshio flows eastward out of the East China Sea into the Pacific Ocean south of Kyushu Island. The third array was placed off Miyake Island about 60 kilometers south of Tokyo.

The time scales of interest in harnessing the Kuroshio power range from 1 hour to a few tens of years (the durability of most of the large-scale offshore installations is thought to be around 30 years). The horizontal space scales of interest in harnessing the Kuroshio power should range from several tens of meters to several tens of kilometers because the dimensions of a power unit such as a rotor should be several tens of meters and a power plant should comprise tens to hundreds of units that are deployed over a distance of several tens of kilometers.

AIR-SEA INTERACTION PROJECT AND THE EFFECT OF THE KUROSHIO ON WEATHER PROJECT

These two new projects that were added in 1986 are really a continuation of research that has been going on for a number of years. Aside from typhoons, many of the weather systems that affect Japan develop in the East China Sea where, in winter, very cold dry air moving southward from Siberia flows out over the East China Sea southwest of Japan. This is the area where the warm waters of the Kuroshio mix with the colder waters of the East China Sea. The cold dry air picks up tremendous amounts of heat from the warm waters of the Kuroshio. The resulting convective activity in the atmosphere spawns storms that move northeastward over Japan. The Japanese call the area the womb of storms. To improve weather forecasting in Japan, the Japanese meteorologists need to know more about the effects of changes in the Kuroshio on the development of storms in the East China Sea.

Wayne V. Burt received his Ph.D. from Scripps Institute of Oceanography in 1952 (UCLA). Dr. Burt was Science Attache for Oceanography and Meteorology in the American Embassy in New Delhi, India, from October 1986 to April 1987. Previously, he was a professor at Oregon State University and served as a liaison scientist of oceanography and meteorology for the Office of Naval Research, London, from 1979 to 1980. Dr. Burt's current interest is in air-sea interaction.

WHAT IS GOING ON IN THE La_2CuO_4 SUPERCONDUCTORS?

Earl Callen

The ceramic cuprate $(La_{1-x}Sr_x)_2CuO_4$ is an antiferromagnetic insulator when the Sr concentration is below 1 percent, a spin glass for .01 < x < .02, and a superconductor at higher Sr levels. Band calculations show a two-dimensional, strongly mixed Cu(d)-O(p) band from planar Cu-O atoms. The bandwidth is wide--between 4 and 9 eV depending on the calculation--several times the correlation term U in the Hubbard Hamiltonian, but La-Sr "214" behaves like a narrow-band, strongly correlated system. Neutron diffraction and Raman scattering evidence support a picture of strong magnon-electron interaction in normal material giving way at higher Sr concentrations to antiferromagnetic fluctuations in Cu spins superexchange coupled through planar O. Fluctuations in the spin system may be the glue coupling electrons into Cooper pairs in the superconductor. Hall data at low Sr concentrations are consistent with a Mott-Hubbard insulating gap model. At higher Sr concentrations the Hubbard gap presumably collapses and the band model prevails; the electronic properties are those of a two-dimensional material of extremely low Fermi energy.

INTRODUCTION

Progress in superconducting ceramics requires understanding interrelated systems of oxide superconductors. To break the world's record with the ultimate high T_c compound it will be necessary to figure out what is going on in La_2CuO_4. Especially so because the latter may be the primary host for all the high T_c Cu oxides so far discovered. This article will dwell on doped La_2CuO_4 in spite of its now-shamefully-low critical temperature of only 40 K.

It was on the Ba-La-Cu-O system that Bednorz and Müller (Ref 1) made their monumental discovery. But the Bake Off did not really get heated up until the University of Tokyo group, Tanaka, Kitazawa, Uchida, and others (Ref 2), painstakingly separated the several mixed phases and announced confirmation of the R=0 evidence by Meissner effect measurements on the superconducting $(La_{1-x}Ba_x)_2CuO_4$ phase. Soon thereafter Kishio, Kitazawa, and others (Ref 3) discovered that Sr and Ca could equally well be substituted. It was first reported that the critical temperatures of the three substitutions differed; it now develops that the three compounds have the same transition temperature (Ref 4). The Ba- and Ca-substituted compounds tend to contain large amounts of oxygen vacancies, which reduce the transition temperature.

Of course a lot of progress has been made since those early days. As preparation techniques have gotten better and materials have improved, as knowledge has grown

and insight deepened, a lot of what was once confused has now become mysterious. Figures 1 and 2 illustrate the point. Figure 1 is a compilation of the older resistivity data. What was nominally the same material seemed to be behaving in some laboratories like a semiconductor, in other laboratories like a superconductor, and a lot in-between.

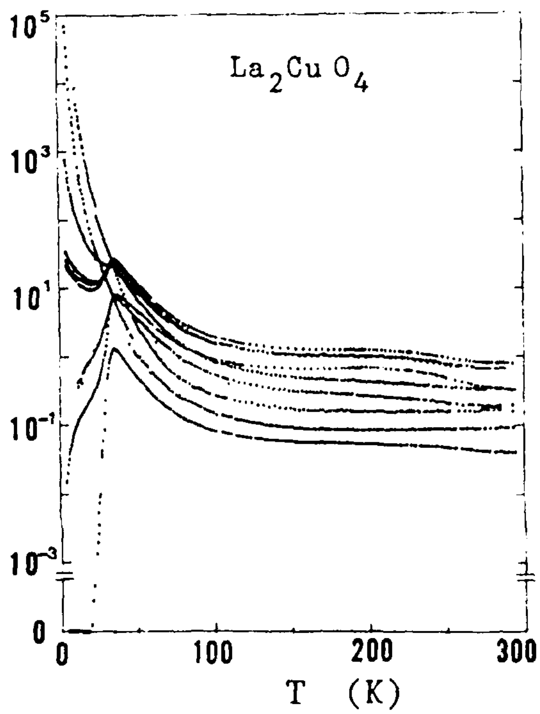


Figure 1. Compilation of early resistivity data of a number of laboratories. This was before it was recognized how sensitive the electronic properties are to impurities.

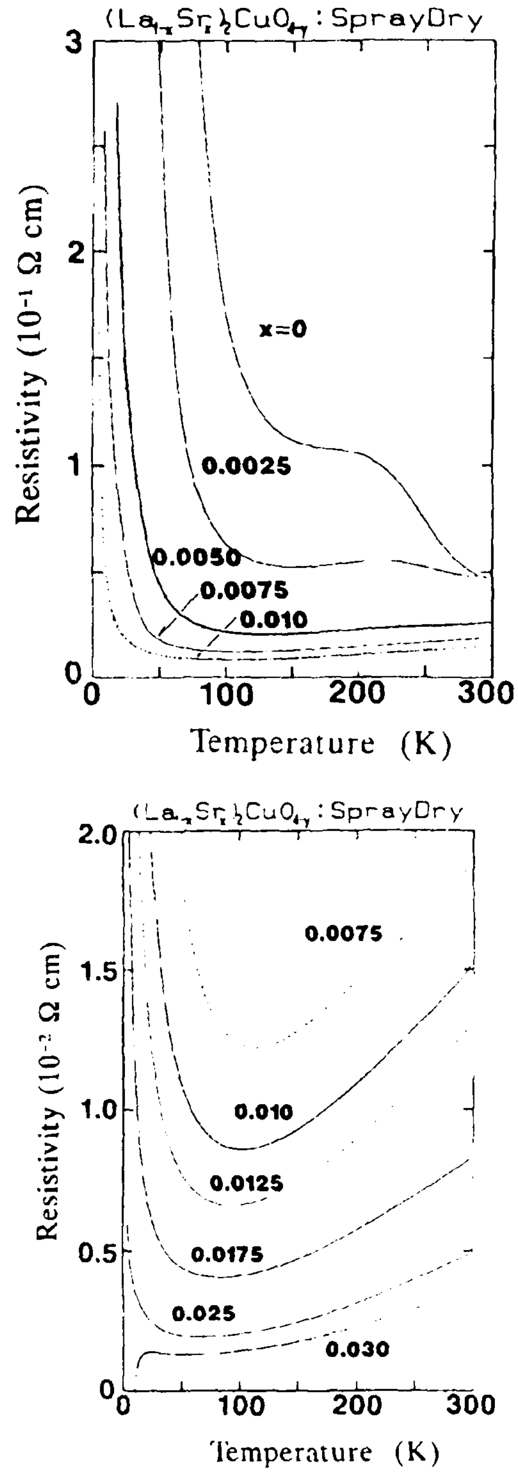


Figure 2. Resistivity versus temperature of $(La_{1-x}Sr_x)_2CuO_4$ for various x. Data and figure courtesy of Tokyo University group.

ELECTRONS AND MAGNONS

Figures 2(a) and (b) represent resistivity data on $(La_{1-x}Sr_x)_2CuO_4$, with the Sr doping carefully controlled (Ref 5). It is appropriate to refer to the alkaline earth substitution as "doping" because the host material is reasonably characterized as some kind of insulator or semiconductor [see the x = 0 curve of Figure 2(a)] and because the Sr concentrations are low. In fact one of the most striking features of Figure 2 is the dramatic change in the character of the resistivity curves with very small doping: from insulator to superconductor with only 3 percent substitution! This surely has to be explained.

From a chemical viewpoint one balances valence. La is a 3+ ion. Substitution by a 2+ alkaline earth should require that a normally 2+ Cu ion shift to 3+. This allows for charge fluctuations and conductivity in the Cu-O planes. But how does this picture explain the extreme sensitivity to doping concentration and the sudden change in character?

The phase diagram of Figure 3 shows that chemical valence is far from the whole story. Unsubstituted La_2CuO_4 is an insulator and is three-dimensionally antiferromagnetically ordered below 250 K (Ref 6). Alkaline earth substitution severely suppresses antiferromagnetic ordering, the Néel temperature falling from 250 K to almost 0 K at less than 1 percent doping. We show the diagram for Sr substitution (Ref 5,7), but the first studies, by Fujita et al. (Ref 8), were on the similar Ba case. Kitaoka et al. (Ref 9) confirmed the picture by nuclear quadrupole resonance (NQR) on the Ba-substituted compound. Watanabe et al. (Ref 10) (also by NQR) and others (Ref 10) proposed the spin-glass-like phase in the 0.01 < x < 0.025 composition range. At doping beyond 2.5 percent the system undergoes an insulator-to-metal transition (Ref 11) and becomes a superconductor (Ref 1,2,12).

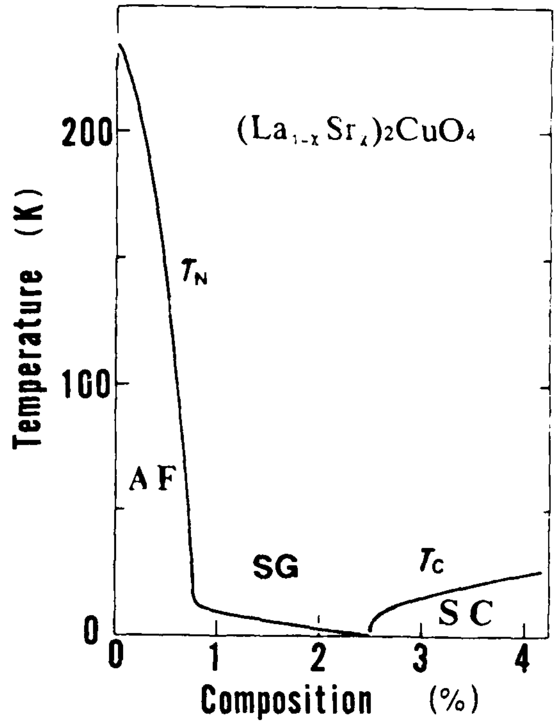


Figure 3. Electronic phase diagram of $(La_{1-x}Sr_x)_2CuO_4$. Below the Néel temperature, T_N, electrons order antiferromagnetically (AF). SG is a spin glass phase, with "frozen" electronic moments on Cu sites but no long range order. As the temperature is increased the SG phase transforms continuously into the magnetically disordered paramagnetic phase. T_c is the critical temperature below which the material is a superconductor, with Cooper pairs of electrons ordered over a coherence length. Data and figure courtesy of Tokyo University group.

Neutron scattering has been performed on the undoped and low doped "214" compound by Yamaguchi et al. (Ref 13), Vaknin et al. (Ref 13), Endoh et al. (Ref 14), and many others. See Reference 14 for numerous references to

the neutron diffraction literature. Neutron scattering is such a powerful tool that it is worthwhile to consider its evidence with care. The magnetic moment, approximately 0.35 μ_B, resides on the Cu. In undoped La_2CuO_4 the nearest neighbor exchange that couples spins (S = 1/2) in the Cu-O planes is 10^4 times as large as the exchange interaction between spins in adjacent planes. Above the Néel temperature the dynamical, energy-integrated scattering of neutrons is that of a two-dimensionally correlated system. But unlike other 2D systems such as K_2NiF_4, as the temperature is lowered to the Néel temperature the transition from 2D dynamical scattering to 3D Bragg scattering is broad and gradual, apparently driven, strangely, by the small 3D coupling. Ionic magnetic moment is independent of Sr concentration, but at room temperature the correlation length of the two-dimensional antiferromagnetic correlations within the Cu-O sheets drops from 200 Å in the undoped material to 14 Å in $La_{1.97}Sr_{0.03}Cu_{0.95}Li_{0.05}O_4$. Aharony et al. (Ref 15) conjecture that holes introduced by Sr doping lie on oxygens in the Cu-O planes. This results in ferromagnetic coupling between planar coppers competing with the antiferromagnetic coupling in the pure material. As for superconductivity, an important result of the neutron diffraction is the energy of the magnetic interaction; it is large--large enough to qualify as the glue between electrons. And the Cu^{2+} spins are seen by the neutrons to be strongly coupled to the charge carriers.

Photoemission (Ref 16) and x-ray absorption studies (Ref 17) on material in the nonsuperconducting range are consistent with the neutron diffraction evidence. The Cu 3d electrons are found to be localized, with $3d^9$ configuration independent of doping. This is presumably due to strong Coulomb repulsion on the same Cu site.

Raman scattering peaks are not unambiguous in identification, and Lyons et al. (Ref 18) properly deposit the caveat that the broad, only-weakly-temperature-dependent peak observed in the Raman spectrum of undoped, antiferromagnetic La_2CuO_4 could possibly be due to some mode other than two-magnon scattering, such as an exciton. But the agreement with selection rules imposed by interaction between spin waves and the electromagnetic field of a light wave and the factor of two agreement with the neutron diffraction results are plausible and suggestive if not compelling. Raman scattering is not an accurate quantitative probe of spin wave dispersion; it suggests an even larger in-plane exchange constant ($J \simeq 1{,}100$ cm^{-1}) than does neutron scattering ($J \approx 590$ cm^{-1}).

The Cu compound is behaving differently from isostructural transition metal oxides La_2NiO_4 and La_2CoO_4. In the latter compounds, also insulators, doping makes localized, nonconducting states in the gap. The insulating state persists up to 40 or 50 percent doping (Ref 19). But in the Cu case, as Figure 2 shows, even the smallest substitution of Sr creates free carriers. At x = 0.0025, electrons localized at low temperatures convert to mobile carriers at 100 K or so. With increasing Sr concentration the localization temperature decreases.

The above measurements were on low doped "214s". In the superconducting phase are there still magnetic moments on the Cu ions? That is implied; as noted above, at lower Sr concentrations the ionic moment is independent of doping level. Are there short range spin correlations? It is an important question, particularly because many theoretical models of high T_c superconductivity invoke antiferromagnetic fluctuations as a mechanism for electron-electron coupling (Ref 20). (In the

90-K $YBa_2Cu_3O_{7-x}$ series, small changes of x also drive a remarkable decrease of T_c and a subsequent transition to an antiferromagnetic insulating state.) The proximity of antiferromagnetism, the neutron diffraction and Raman evidence, antiferromagnetic metal-insulator transitions in other transition metal-oxides, are taken by many (but not by all!) as a big hint from Nature about the superconductive pairing mechanism.

BAND THEORY OF La_2CuO_4

Our understanding of ceramic high T_c superconductivity is still in the disordered high temperature state. How does one comprehend a field that has not yet gone through the phase transition to understanding? Why is La_2CuO_4 an insulator? As we shall see, on the one-electron picture it should be a metal. There is an alternative approach--which also has its problems. But first let us review the band theory, from which we can learn much, look at where it goes wrong, and then look at the alternatives.

In the Hamiltonian for the electrons and ions in a crystal, terms involving the electrons are single particle in electron coordinates except Coulomb interactions, e^2/r_{ij}, between the electrons. To reduce this many-body ($N = 10^{23}$) problem to a tractable single-particle problem, band theory calculates the potential of all the electrons but the one of concern as though the electrons were frozen in their average charge density distributions. This Hartree-Fock approximation loses sight of electron-electron correlations--the positions and Coulomb energy with all the other electrons depend upon the position of the electron whose wave function is being calculated; i.e., there is no unique "potential" of the other electrons. The Hartree-Fock approximation is remarkably good when the overriding features are lattice symmetry, kinetic energy, and ionic potential, all of which it diagonalizes exactly. It is best in metals of wide bandwidth, where the electrons are not so strongly correlated in their motions. It goes wrong in narrow-band, highly correlated systems; in these the electron-electron interactions must be treated more carefully.

Band theory calculations of La_2CuO_4 have been carried out by Mattheiss (Ref 21), Freeman and numerous coauthors (Ref 22,23,24), and Park et al. (Ref 25). A conclusion common to all the band calculations is that conductivity takes place in a strongly hybridized band of states arising from wave functions of atoms in the two-dimensional Cu-O planes. The band is flat; it shows almost no dispersion along the direction normal to the planes, like the band structure of an isolated layer of Cu and O atoms. But there is great dispersion of e(k) in the planes. Freeman et al. describe a band at the Fermi level of mixed $Cu(d_{x^2-y^2})$ -- $O(p_{x,y})$ character. Cu atoms in the planes accumulate some excess electronic charge density and this is compensated for by holes in the p-d hybrid band. Sr doping contributes additional holes to this band.

In all calculations band theory places the Fermi level somewhere near or a bit below a half-filled band, in a region of some density of states. This would be a metal, not an antiferromagnetic insulator. Spin-polarized calculations have, to my knowledge, not been done on La_2CuO_4, and with good reason. There is much better hope for such an approach in NiO than in the "214," but a spin-polarized band calculation (Ref 26) for NiO produces a bandgap of less than 1 eV, too small to explain the

optical data (Ref 27,28). And in CuO, which like NiO is also an antiferromagnetic insulator in defiance of band theory, an assumed antiferromagnetic ground state is unstable altogether (Ref 25).

If band theory is not right, it may be at least suggestive of trends and differences between materials. This is the emphasis of Park et al. (Ref 25). Those authors have calculated densities of states and dispersion curves for NiO, CuO, La_2CuO_4, and several other of the superconducting copper oxide ceramics:

NiO and CuO. This is a nonmagnetic calculation, and the Fermi level lies (at about 0.5 Ry) within the band--that old embarrassment remains. There is a gap in the densities of states of both NiO and CuO at about 0.26 Ry. The states below the gap are p-d bonding states, mostly of O(p) character. The states above the gap are p-d antibonding states, mostly of Ni(d) or Cu(d) character.

La_2CuO_4. In La_2CuO_4 (and in $La_2CaCu_2O_6$), in contrast, there is no gap between the bonding and antibonding p-d bands. This implies that the O(p) and Cu(d) states lie closer together in energy and hybridize more in La_2CuO_4 (and in $La_2CaCu_2O_6$) than in NiO or CuO.

Trends. Mattheiss (Ref 21) has emphasized that a characteristic feature of the high T_c oxides is their nearly complete overlap in energy and hybridization of the O(p) and Cu(d) states. This is confirmed by several experiments (Ref 13,29,30). Terakura et al. make the same point by plotting the centers of gravity of the local densities of states of the coppers and oxygens in a series of compounds. Their results are shown in Figure 4. Energies are measured from the Fermi level. In the ceramics, the coppers focussed on are the important ones in the Cu-O planes. A strong trend is evident in the figure. The large separation between the levels in NiO is greatly reduced in CuO and still smaller in La_2CuO_4 and in $La_2CaCu_2O_6$. (In the latter two compounds, O 1 indicates the oxygen in the Cu-O planes and O 2 the apex oxygen.) $La_2CaCu_2O_{6+x}$ is a metal for all x but not a superconductor (Ref 31).

THE METAL-INSULATOR TRANSITION: THE TROUBLE WITH BAND THEORY

Consider the compounds TiO, MnO, FeO, CoO, and NiO. All crystallize in the NaCl structure--cubic with alternate ions on successive sites. TiO is a metal. MnO, FeO, CuO, and NiO are insulators and antiferromagnets. The room temperature conductivity of TiO is 10^{20} times as large as that of MnO. Band theory predicts that all are metals. But band theory is done by machine calculation; we can gain insight from simpler crystal field considerations. For these 2+ ions the numbers of d electrons are: Ti ($3d^2$); Mn ($3d^5$); Fe ($3d^6$); Co ($3d^7$); Ni ($3d^8$). In the strong cubic crystalline field of the oxide the tenfold-degenerate 3d band is split into a lower sixfold-degenerate t_{2g} subband and an upper fourfold-degenerate e_g subband. Because of the narrowness of the d band, the two subbands are presumed to be separated in the strong crystal field. Now let us populate the subbands in each case. TiO works out fine: two electrons in a subband that can hold six electrons--a metal. FeO works out fine; its six electrons fill the lower subband, and it is an insulator. But how to explain that MnO, CoO, and NiO are insulators? Mn^{2+} and Co^{2+} have an odd number of electrons. No (unmagnetized) assignment of crystal field splittings can dodge the Kramers

degeneracy. And in the case of Ni, six of its eight electrons should fill the t_{2g} subband and the remaining two should populate only half the states of the e_g band.

Where did band theory go wrong? How did the replacement of the electron-electron Coulomb interaction by an interaction with an average charge density lead to such dramatic failure?

The problem was highlighted long ago by de Boer and Verwey (Ref 32) and greatly elaborated on by Mott (Ref 33). Here is de Boer and Verwey's argument: Imagine a simple cubic array of H atoms, close together so that the electron wave functions overlap substantially. The atomic states broaden into a band. The kinetic energy is lowered by having each electron spread through the entire crystal in a Bloch wave. The band is half-filled (one electron in two states per atom) and there is conductivity. This allows for density fluctuations; occasionally two electrons pass on the same site. This costs some Coulomb energy, but it is more than compensated for by the reduction in kinetic energy. Now imagine gradually increasing the interatomic distance of the cubic array. The band picture would suggest that as the overlaps decrease, the band gets continuously narrower but remains half-filled. The effective mass of the carriers should increase continuously and only vanish at infinite separation. Conductivity should diminish continuously.

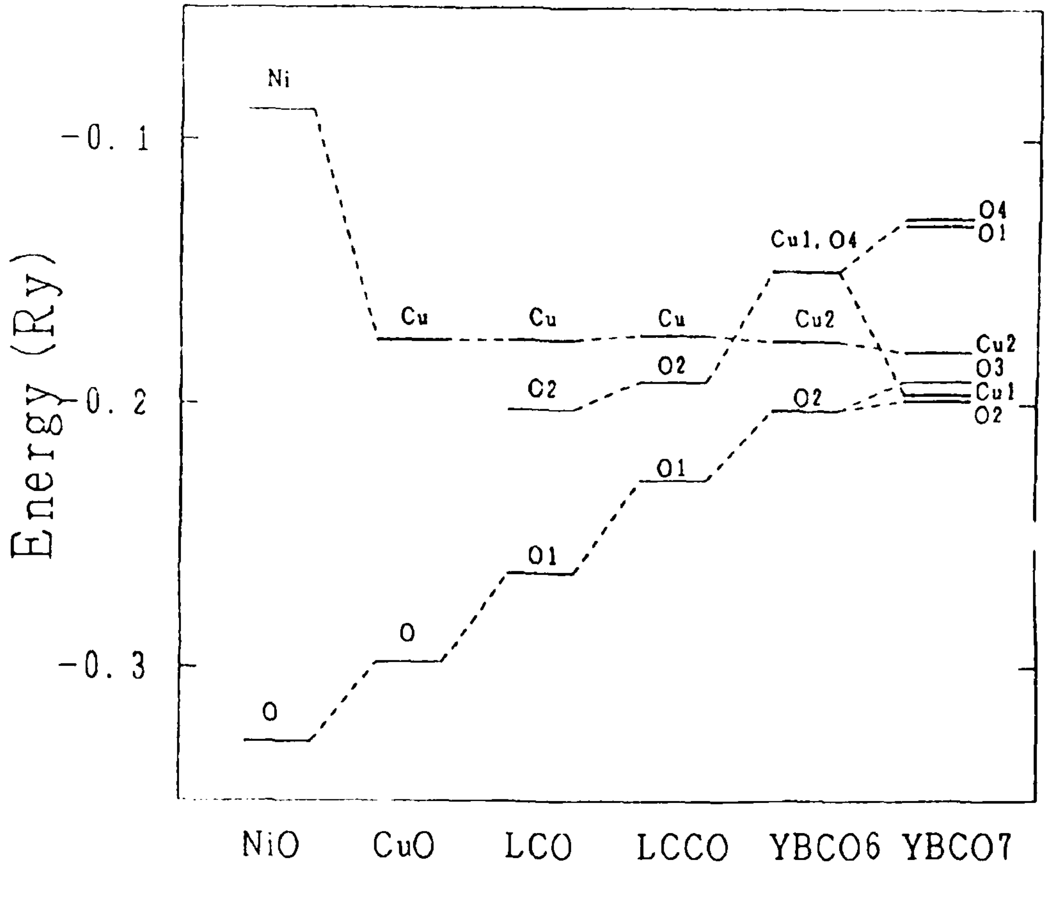


Figure 4. "Center of gravity" of local densities of states of planar Cu(d) states and planar O(p) states, in a series of compounds. In general, the smaller the separation of the two energies, the higher the critical temperature (from Ref 25).

But this is not the picture one comes to from the other limit, starting with hydrogen atoms at infinite separation. At large distances the correct state is neutral atoms and localized wave functions, with one electron on each atom. The kinetic energy reduction of Bloch waves is too small to compensate for the expensive increase in Coulomb energy. There is no conductivity.

So as the crystal is compressed a crossover must occur somewhere. The appropriate description of the ground state must switch from a set of localized electrons on neutral atoms at large separation to a set of Bloch waves, with mobile electrons traversing the crystal below some critical separation (or above some critical electron density). In the box we give Mott's description of the criterion for this transition.

An important feature of the Mott transition is that it is abrupt; it has positive feedback. Suppose the system to be just marginally insulating and an electron gets free. The free electron screens the potentials and induces others to escape, and this avalanches. Temperature can induce delocalization and a Mott transition in some semiconductors. (The treatment is modified by introduction of a dielectric constant κ as in the expression in the box for the screened Coulomb energy.)

Mott suggested why a conductivity transition should occur in only certain materials. In a broadband material the reduction of kinetic energy by delocalization is large--large enough to overcome the increase in Coulomb energy between electrons in ionized states in a partially filled band. The metallic state is then favored. Only in those materials in which the bands in the vicinity of the Fermi energy are narrow, so that the kinetic energy reduction by delocalization is small, is the Mott insulator energetically favored. In practice such narrow bands at the Fermi energy are found in the transition metal oxides. In the pure transition metals the s band is broad and overlaps the d band. But in the transition metal oxides the s band of the transition metal ion is lifted some 5 eV above the Fermi energy.

Slater (Ref 34) suggested what seemed like a way out. The transition metal oxides are antiferromagnets. Antiferromagnetic spin ordering--up, down, up, down on successive sites--doubles the unit cell, reduces the Brillouin zone in half, and can put a gap at the Fermi surface. NiO will be an insulator if there is a gap in the density of states between the up and down exchange split halves of the e_g band. MnO will be an insulator if the exchange splitting exceeds the crystal field splitting. (But this argument creates a problem for FeO. If the exchange splitting is as strong in FeO as in MnO, then FeO becomes metallic on the band model; we shall have to adjust constants carefully.) For CoO a tetragonal distortion must be invoked.

A problem with the Slater mechanism is that these materials all remain insulators far above their Néel temperatures, at which the antiferromagnetism vanishes.

STRONGLY CORRELATED SYSTEMS: THE HUBBARD MODEL

Band theory fails to explain why the transition metal oxides are insulators, but Hubbard shows how electron-electron correlation can do the trick. Hubbard's analysis (Ref 35) is based on a drastically simplified, single-band Hamiltonian

$$H = \sum_{i,j} \sum_{\sigma} t_{ij} c^{\dagger}_{i\sigma} c_{i\sigma} + U \sum_{i} n_{i\uparrow} n_{i\downarrow}$$

Thomas-Fermi Screening and the Mott Transition

We assume the system to be metallic. Conduction electrons screen the positive charge of the proton at each site. If the screened Coulomb potential has a bound state, the ion will recapture an electron and the system will not be a metal as assumed. A bound state exists if the radius of the orbit in the metal exceeds that of the first Bohr orbit. The self-consistency criterion is then that the radius of the orbit, which will be something like the reciprocal of the screening constant, be less than the Bohr radius. Mott's mechanism is a bit different from that of de Boer and Verwey, but the conclusion is much the same. Mott suggests that if the screening is low enough to allow a bound state, free electrons and free holes combine to form an exciton, a neutral, nonconducting pair.

Because of conduction electron screening, the Coulomb energy of interaction between the two charges (in a medium of dielectric constant κ) is

$$\frac{-e^2}{\kappa r} e^{-\alpha r}$$

Solving Poisson's equation, with the n electrons per unit volume and electron states populated up to the Fermi level, one finds the Thomas-Fermi screening constant α to be

$$\alpha^2 = \frac{4 \; me^2 \left(\frac{3n}{\pi}\right)^{1/3}}{\hbar^2}$$

The radius of the first Bohr orbit of hydrogen is

$$a_0 = \hbar^2/me^2$$

Mott's criterion for the transition, that the radius of the exciton orbit approximately equals the Bohr radius, then reduces to

$$n^{1/3} a_0 \simeq 0.2$$

At ionic separation such that the average distance between electrons, $n^{-1/3}$, exceeds some small multiple of the Bohr radius (with such a calculation we cannot be too fussy about the numerical coefficient), the system should be an array of neutral atoms, nonconducting. As it is compressed further, as the electron density increases, kinetic energy overrides Coulomb repulsion and the array transforms to a metal. This was de Boer and Verwey and Mott's beautiful insight!

The first term represents the band energy. t_{ij} is the Fourier transform of the Bloch single particle energy $\epsilon(k)$. The energy is not diagonal in the localized Wannier states on sites i and j, in spin σ. The operator $c_{i\sigma}$ annihilates an electron of spin σ in the Wannier state centered on site i. The number operator is $n_{i\sigma} = c^{\dagger}_{i\sigma} c_{i\sigma}$. In the second term, U represents the Coulomb repulsion between two electrons (of opposite spin) on the same site. Note that the degeneracy of the d band has been dropped. Because the band is assumed to be nondegenerate, two electrons can occupy the same Wannier function only if their spins are antiparallel. This is indicated in the spin indices of the Coulomb repulsion term. Of course the real Coulomb repulsion is of 1/r form and has infinite range. The delta-function form of the Coulomb on-site interaction and the assumption of a nondegenerate band have as their justification only that they make the model simpler. Even as it is, the problem is so complicated as to so far defy complete solution. But it contains the seeds of the competition between band energy and Coulomb repulsion.

In the atomic limit (infinite U, or zero bandwidth) the Hubbard model places one electron on each atom. There are two bands, due to spin degeneracy, but which spin the electron has on each site is irrelevant in this limit. The two bands are sharp in energy and are split by energy U. The lower band is completely filled and the upper empty, an insulator of infinitely separated hydrogenlike atoms. As the atoms are brought together, i.e., as bandwidth/Coulomb energy (t/U) is increased, the gap (often called the Hubbard gap) between the two bands decreases. Spin arrangement now becomes significant; the ground state of the insulator can be antiferromagnetic. At some definite ratio of bandwidth to Coulomb energy the gap goes to zero and the system becomes a metal. As the model stands the gap does not collapse dramatically with reduction of lattice constant. There is no cooperative feedback mechanism in the model that could induce a sudden transformation. Nor is it to be expected that with thermal excitation the Hubbard model as it stands will exhibit a metal-insulator transition. On the other hand, the model does predict a very strong dependence of spin ordering, or charge ordering, and gap width, on doping and deviation of Fermi level from the half-filled band.

In the extreme metallic limit of infinite bandwidth, or zero Coulomb repulsion, the Hubbard model has as its ground state the band states, filled two each (one with spin up and one with spin down) up to the Fermi level at the half-filled band.

MAGNETITE

Here is an example of strong Coulomb repulsion in a narrow half-filled band explaining a metal-insulator transition. It is of particular interest to this commentator. Cullen and Callen (Ref 36) have shown that increasing the size of the unit cell and thereby reducing the Brillouin zone can account for the Verwey (the same Verwey) transition in magnetite. It is like Slater's idea, but in magnetite, Fe_3O_4, it is not spin ordering but charge ordering that enlarges the unit cell. Verwey (Ref 37) described the ordered, low temperature phase to have alternate layers of Fe^{3+} and Fe^{2+} ions. Since there can be no electron hopping in a plane that is either all Fe^{3+} or all Fe^{2+}, the ordered state should be an anisotropic insulator. Verwey argued that the iron ions are disordered in the high temperature phase, allowing electron hopping and conductivity.

Cullen and Callen treat the electrons on the Hubbard model. The lowest crystal field-split band can hold two electrons and is just half-filled. Charge ordering (there are multiple charge ordering parameters, and they are fractions; ionicity is not complete) increases the unit cell and creates a gap at the Fermi surface. Scattering diffraction patterns confirm a greatly enlarged unit cell, with a complex array of fractional charges. And in magnetite, unlike the simple antiferromagnetic oxides, the metal-insulator conductivity transition coincides with the charge density wave transition. Furthermore, doping the material away from a half-filled subband very quickly suppresses the charge ordering and the metal-insulator transition. (There is also a ferrimagnetic Curie point in magnetite, but it is at a far higher temperature and has nothing to do with the Verwey transition.) Another satisfying feature of the model is the abruptness of the transition, which is either first or second order. (The experimental situation is not entirely clear; the order of the transition seems to depend sensitively on small deviation from stoichiometry.)

BACK TO La_2CuO_4

Unlike band theory the Hubbard model, as we have seen, not only can account for La_2CuO_4 being an insulator but at the same time can predict the observed antiferromagnetism. The model can probably account for the severe drop of Néel temperature with Sr doping. And it can describe the collapse of the gap and the metallic conductivity at higher doping density. (But superconductivity is something else again.) These are irresistible inducements and so most theoretical efforts build on some form of narrow-band approach, in one way or another stressing correlations. For example, Anderson (Ref 20), in justifying his resonating valence bond picture, argues that because La_2CuO_4 is an insulator, Coulomb repulsion must be large compared to bandwidth. Huang and Manousakis (Ref 20), who use the Hubbard Hamiltonian, state that "typically $U >> t$, ... $t = 0.5$ eV." Huang and Manousakis take $U = 2.5$ eV, and $t/U = 0.2$.

Huang and Manousakis cite Mattheiss (Ref 21) and Yu, Freeman, and Xu (Ref 22). But as we have said, in their earlier calculations Freeman et al. (Ref 22,23) describe a strongly hybridized band at the Fermi level of width 3 eV. In later papers (Ref 24) they report the width of this band to be 9 eV. And Park et al. (Ref 25) find a bandwidth of 4 or 5 eV. How does one get from 9 eV or 4 eV down to 0.5 eV and small t/U? In spite of the evidently strong Cu(d)-O(p) mixing, arguments are made for a reduced direct d-d transfer integral, and with cause or not, the bandwidth is divided by the number of neighbors. The conventional justification for the Hubbard model seems to be problematic, but it evidently has a validity beyond its derivation. What drives strong correlations in a wide-band material? Perhaps in the answer to that question about the insulating regime of the concentration range lies some hint about the motivating force for electron pairing in the higher doped superconducting regime.

A particular feature of the cuprate superconductors is the omnipresent copper-oxygen planes. Park et al. (Ref 25) (see Figure 4 and the discussion in the section on band theory) emphasize the closeness in energy of the Cu(d) and O(p) states; the smaller the energy difference the higher the transition temperature. Perhaps the ultimate room temperature superconductor will be a material in which the two local densities of states are degenerate.

Pressure measurements and band theory deformation potential calculations would be suggestive.

It seems too much of a coincidence (or by Ockham's Razor) that the same materials that are superconductors should be antiferromagnets. A commonly held view is that in the insulating regime there is some form of superexchange antiferromagnetically coupling the Cu moments through the intermediate oxygens in the plane. And this same spin coupling mediates the electron pair formation in the superconductor.

The picture we have then is some kind of Mott insulator driven by antiferromagnetism in pure La_2CuO_4. Adding Sr introduces holes in the valence band, suppresses the spin density wave, and soon collapses the antiferromagnetism and the gap. Perhaps the holes are concentrated in the planar oxygens, clogging up the superexchange. Yet in the metallic range a residue of the spin coupling remains to push the superconductivity. But of course this is not a theory; it is only a trail to be scented out.

In any event, getting the right answer is a strong argument. In the low-doping, insulating range of Figure 2 the Hubbard picture supports other experimental findings as well. Figure 5 shows the magnetic susceptibility for various doping concentrations (Ref 38). The x = 0 curve has a bump at 275 K, the antiferromagnetic transition temperature. Although it does not show up in the figure, the bump is reported to decrease in magnitude and to shift to a lower temperature as the Sr concentration is increased and the spin density wave suppressed. Figure 6 (Ref 5,7,39) shows the temperature dependence of the Hall coefficient for several Sr doping concentrations in $(La_{1-x}Sr_x)_2CuO_4$. From the positive sign of the Seebeck and Hall coefficient, the majority carriers are indeed holes. Their number seems to be pretty much independent of temperature, as one would expect in a doped semiconductor. The carrier density is low, about 10^{21} cm^{-3}.

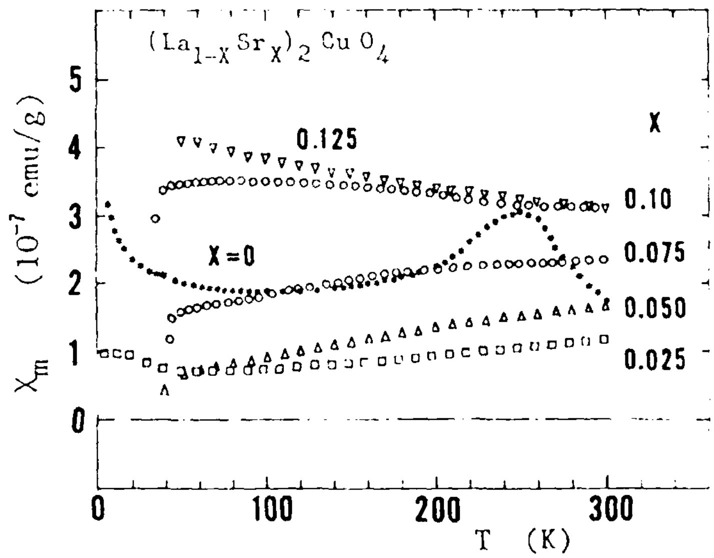


Figure 5. Magnetic susceptibility versus temperature of $(La_{1-x}Sr_x)_2CuO_4$ for various x. The bump at around 275 K in the x = 0 curve is the antiferromagnetic transition. (At the phase transition the susceptibility peaks.) Although it is not evident in the data, the peak is reported to shift rapidly to lower temperature with increasing Sr concentration, following the phase diagram of Figure 3 (from Ref 38).

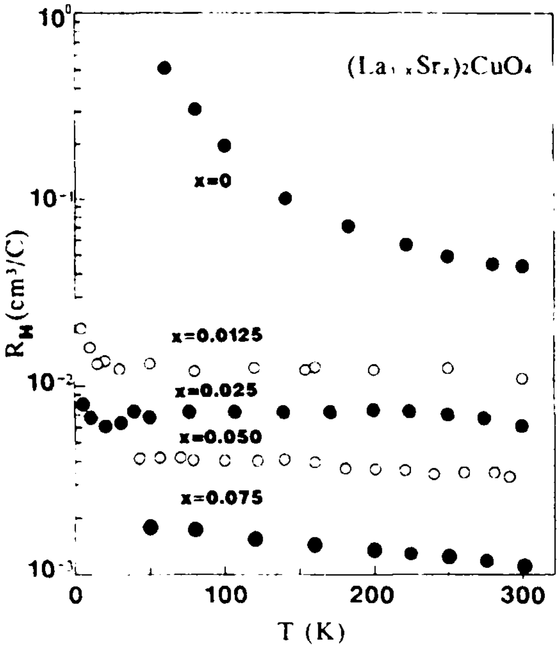


Figure 6. Hall coefficient versus temperature for various Sr concentrations. The majority carriers are holes, and the number of holes increases (decreasing Hall resistivity) with doping. Apart from the x = 0 data, the Hall coefficient is pretty much temperature independent. In the low concentration range the data are consistent with the Mott-Hubbard picture, with Sr creating holes in the Hubbard band below the gap [from *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988. To be published in 1989. Used with permission of the Materials Research Society (Ref 5)].

The reciprocal of the Hall coefficient is proportional to the number of carriers (holes) on a one-band model, and the number of holes should be proportional to the number of impurities. Figure 7 shows the relationship between (room temperature) reciprocal Hall coefficient and Sr concentration in the copper compound (Ref 5,7). There is a linear range below 5 percent doping, and perhaps above, but with a different slope. That something different is happening after 5 percent Sr substitution and at higher doping concentration is confirmed by room temperature optical (infrared in this case) reflectivity (Ref 40). From the reflectivity edge one finds the plasma frequency. The square of the plasma frequency should also be proportional to the number of carriers, but we see in Figure 7 that it is not rising linearly with Sr concentration; it is constant.

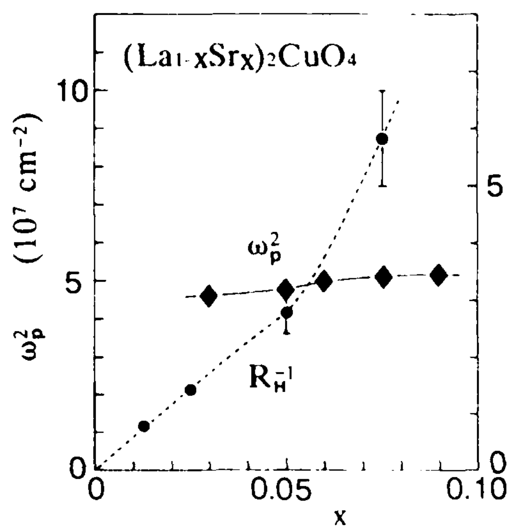


Figure 7. The reciprocal of the room temperature Hall coefficient (right ordinate and circles) and square of the plasma frequency (left ordinate and diamonds) versus Sr concentration in the normal La cuprate. On a simple gap model both should be proportional to the number of carriers. The Hall data are linear but change slope at about 5 percent substitution. The optical reflection edge data would seem to suggest that the number of carriers is independent of doping, but the high frequency data can be rationalized by a Fermi level, density of states argument (see text) [from *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988. To be published in 1989. Used with permission of the Materials Research Society (Ref 5)].

A plasma reflection edge independent of the number of carriers cannot be explained easily on the Hubbard-Mott model. Uchida et al. (Ref 5,7,39) interpret this and their other optical data as meaning that, unlike the Hall conductivity, which is dc, the reflection edge measures high frequency response. The constancy of the plasma frequency is not inconsistent with the model of a collapsed gap in the metallic phase. In this regime, the square of the plasma frequency is proportional to the square of the Fermi velocity times the density of states at the Fermi level. Doping lowers the Fermi level and reduces the density of states, but this is compensated for by an increase in Fermi velocity. As a result the plasma frequency does not depend strongly on doping concentration in the metallic regime.

Once in the collapsed, metallic state beyond 5 percent doping or so, we can understand in conventional terms several unusual features of the behavior of $(La_{1-x}Sr_x)_2CuO_4$ in both the high temperature, normal phase and in the superconducting phase. The key is the extremely low Fermi energy and the highly anisotropic Fermi surface. Kresin, Deutscher, and Wolf (Ref 41) demonstrate this. The states at the Fermi surface come from the planar Cu-O layers. As we have discussed, there is almost no dispersion perpendicular to the layers but strong in-plane dispersion in e(k). Thus the Fermi surface is pipelike (but not necessarily circular in cross section), long along the major axis relative to the pipe radius. The effective mass is highly anisotropic. The Fermi energy is 0.5 eV or less. Normally in metals, E_F is about 10 eV. In conventional superconductors the T = 0 gap is a small fraction of the Fermi energy ($= 10^{-4}$). In the cuprates it can be as high as 0.1. While in normal superconductors only a very small fraction of the electrons are paired, in the high T_c cuprates a large fraction of the carriers are paired. Kresin et al. show that the linear temperature dependence of electrical resistivity in the normal phase follows from the low Fermi energy and two-dimensional nature of the phonon spectrum. In normal metals most of the thermal conductivity comes from electrons. But in the cuprates the low Fermi energy results in the phonons being the major channel for thermal current.

HOLD THE PRESSES

We started by apologizing for an interest in the "214" cuprate, a material with a transition temperature of only 40 K. Now as we conclude this article we have a preprint from Aoki et al. (Ref 42) reporting a superconducting transition at 85 to 91 K in $La_{2-x}CuO_{4-y}$. Aoki et al. find that a small but reproducible fraction of their material is superconducting both by resistivity and Meissner criteria. There are three distinct transitions with different magnetic and resistivity signatures, at temperatures of about 10, 40, and 90 K. In some samples there is also a magnetic anomaly, a cusp in the susceptibility, at about 275 K.

ACKNOWLEDGMENT

Among other sources this article draws on two invited talks by Prof. Shin-ichi Uchida of Tokyo University, first at a conference sponsored by the Society of Non-Traditional Technologies and then at the Materials Research Society International Meeting on Advanced Materials, Tokyo, 30 May - 3 June 1988. We benefitted from comments on the manuscript by Prof. Uchida and from conversations with Prof. K. Terakura of the Tokyo University Institute for Solid State Physics (but for the errors we get full credit).

REFERENCES

1. J.C. Bednorz and K.A. Müller, Z. Phys. B **64**, 189 (1986).

2. S. Uchida, H. Takagi, K. Kitazawa, and S. Tanaka, Jpn. J. Appl. Phys. **26**, L1 (1987); H. Takagi, S. Uchida, K. Kitazawa, and S. Tanaka, Jpn. J. Appl. Phys. **26**, L123 (1987).

3. K. Kishio, K. Kitazawa, S. Kanbe, I. Yasuda, N. Sugii, H. Takagi, S. Uchida, K. Fueki, and S. Tanaka, Chem. Lett., 429 (1987).

4. J.B. Torrance and Y. Tokura, Phys. Rev. Lett., submitted June 1988.

5. S. Uchida, H. Takagi, S. Tajima, K. Kishio, T. Hasegawa, K. Kitazawa, K. Fueki, and S. Tanaka, *Superconductivity*, vol 6, Proceedings of the MRS International Meeting on Advanced Materials, Tokyo, May 1988 (to be published in 1989).

6. K. Yamada, E. Kudo, Y. Endoh, R.J. Birgeneau, M.A. Kastner, Y. Hidaka, M. Oda, M. Suzuki, and T. Murakami, Solid State Commun. **64**, 753 (1987); S. Uchida, H. Takagi, H. Yanagisawa, K. Kishio, K. Kitazawa, K. Fueki, and S. Tanaka, Jpn. J. Appl. Phys. **26**, L445 (1987); S. Mitsuda et al., Phys. Rev. B**36**, 826 (1987); N. Nishida et al., Jpn. J. Appl. Phys. **26**, L1856 (1987); G. Shirane, Y. Endoh, R.J. Birgeneau, M.A. Kastner, Y. Hidaka, M. Oda, M. Suzuki, and T. Murakami, Phys. Rev. Lett. **59**, 1613 (1987).

7. H. Takagi, M. Uota, Y. Tokura, J.B. Torrance, and S. Uchida, paper in preparation.

8. T. Fujita, Y. Aoki, Y. Maeno, J. Sakurai, H. Fukuba, and H. Fujii, Jpn. J. Appl. Phys. **26**, L368 (1987).

9. Y. Kitaoka, S. Hiramatsu, T. Kohara, K. Asayama, K. Ohishi, M. Kikuchi, and N. Kobayashi, Jpn. J. Appl. Phys. **26**, L397 (1987); Y. Kitaoka, S. Hiramatsu, K. Ishida, T. Kohara, and K. Asayama, J. Phys. Soc. Jpn. **56**, 3024 (1987).

10. I. Watanabe, K. Kumagai, Y. Nakamura, T. Kimura, Y. Nakamichi, and H. Nakajima, J. Phys. Soc. Jpn. **56**, 3028 (1987); Y.J. Uemura et al., Phys. Rev. Lett. **59**, 1045 (1987).

11. R.M. Fleming, B. Batlogg, R.J. Cava, and E.A. Rietman, Phys. Rev. B**35**, 7191 (1987); R.B. van Dover, R.J. Cava, B. Batlogg, and E.A. Rietman, Phys. Rev. B**35**, 5337 (1987).

12. M. Onoda, S. Shamoto, M. Sato, and S. Hosoya, Jpn. J. Appl. Phys. **26**, L363 (1987).

13. Y. Yamaguchi, H. Yamaguchi, M. Ohashi, H. Yamamoto, N. Shimoda, M. Kikuchi, and Y. Syono, Jpn. J. Appl. Phys. **26**, L447 (1987); D. Vaknin, S.K. Sinha, D.E. Moncton, D.C. Johnston, J.M. Newsam, C.R. Safinya, and H.E. King, Jr., Phys. Rev. Lett. **58**, 2802 (1987).

14. Y. Endoh, K. Yamada, R.J. Birgeneau, D.R. Gabbe, H.P. Jenssen, M.A. Kastner, C.J. Peters, P.J. Picone, T.R. Thurston, J.M. Tranquada, G. Shirane, Y. Hidaka, M. Oda, Y. Enomoto, M. Suzuki, and T. Murakami, Phys. Rev. B**37**, 7443 (1988).

15. A. Aharony, R.J. Birgeneau, A. Coniglio, M.A. Kastner, and H.E. Stanley, Phys. Rev. Lett. **60**, 1330 (1988).

16. A. Fujimori, E. Takayama-Muromachi, Y. Uchida, and B. Okai, Phys. Rev. B35, 8814 (1987).

17. J.M. Tranquada, S.M. Heald, and A.R. Moodenbaugh, Phys. Rev. **B36**, 5263 (1987).

18. K.B. Lyons, P.A. Fleury, J.P. Remeika, A.S. Cooper, and T.J. Negran, Phys. Rev. B37, 2393 (1987); S. Sugai, S. Shamoto, and M. Sato, preprint.

19. J. Gopalakrishnan, G. Colsmann, and B. Reuter, J. Solid State Chem. **22**, 145 (1987).

20. P.W. Anderson, Science **235**, 1196 (1987); P.W. Anderson, G. Baskaran, Z. Zou, and T. Hsu, Phys. Rev. Lett. **58**, 2790 (1987); V.J. Emery, ibid. **58**, 2794 (1987); P.A. Lee and M. Read, ibid. **58**, 2691 (1987); J.E. Hirsch, ibid. **59**, 228 (1987); S.A. Kivelson, D.S. Rokhsar, and J.P. Sethna, Phys. Rev. **B35**, 8867 (1987); D.J. Thouless, ibid. **B36**, 7187 (1987); K. Huang and E. Manousakis, ibid. **B36**, 8302 (1987); C. Gros, R. Joynt, and T.M. Rice, Z. Phys. B **68**, 425 (1987).

21. L.F. Mattheiss, Phys. Rev. Lett. **58**, 1028 (1987).

22. J. Yu, A.J. Freeman, and J.H. Xu, Phys. Rev. Lett. **58**, 1035 (1987).

23. A.J. Freeman, J. Yu, and C.L. Fu, Phys. Rev. **B36**, 7111 (1987); J.-H. Xu, T.J. Watson-Yang, J. Yu, and A.J. Freeman, Physics Lett. **A120**, 489 (1987); A.J. Freeman, C.L. Fu, D.D. Koelling, S. Massidda, T.J. Watson-Yang, J. Yu, and J.-H. Xu, MRS Conf. Report, Spring 1987.

24. A.J. Freeman, J. Yu, and C.L. Fu, Phys. Rev. (Rapid Commun.); A.J. Freeman and J. Yu, *Proc. of Advanced Study Institute on Alloy Phase Stability*, Crete, Greece, 14-27 June 1987; A.J. Freeman and J. Yu, *Proc. Intl. Conf. on Electronic Structure and Phase Stability in Advanced Ceramics*, Argonne National Laboratory, 17-19 August 1987.

25. K.T. Park, K. Terakura, T. Oguchi, A. Yanase, and M. Ikeda, J. Phys. Soc. Jpn. **57**, No. 10, 3445 (1988).

26. K. Terakura, T. Oguchi, A.R. Williams, and J. Kubler, Phys. Rev. **B30**, 4734 (1984).

27. A. Fujimori and F. Minami, Phys. Rev. **B30**, 957 (1984).

28. G.A. Sawatzky and J.W. Allen, Phys. Rev. Lett. **53**, 2339 (1984).

29. T. Takahashi, F. Maeda, H. Arai, H. Katayama-Yoshida, Y. Okabe, T. Suzuki, S. Hosoya, A. Fujimori, T. Shidara, T. Koide, T. Miyahara, M. Onoda, S. Shamoto, and M. Sato, Phys. Rev. **B36**, 5686 (1987).

30. D. van der Marel, J. van Elp, G.A. Sawatzky, and D. Heitmann, Phys. Rev. **B37**, 5136 (1988).

31. J.B. Torrance, Y. Tokura, A. Nazzal, and S.S.P. Parkin, Phys. Rev. Lett. **60**, 542 (1988).

32. J.H. de Boer and E.J.W. Verwey, Proc. Phys. Soc. (London) **49**, 59 (1937).

33. N.F. Mott, Proc. Phys. Soc. (London) **A62**, 416 (1949); Can. J. Phys. **34**, 1356 (1956); Phil. Mag. **6**, 287 (1961); Advan. Phys. **16**, 49 (1967).

34. J.C. Slater, Phys. Rev. **82**, 538 (1951).

35. J. Hubbard, Proc. Roy. Soc. (London) **A276**, 238 (1963); ibid. **A277**, 237 (1964); ibid. **A281**, 401 (1964).

36. J.R. Cullen and E.R. Callen, Phys. Rev. **B7**, 397 (1973); J.R. Cullen, E.R. Callen, and B. Choudhury, Phys. Lett. **38A**, 113 (1972); J.R. Cullen and E.R. Callen, Phys. Rev. Lett. **26**, 236 (1971); Solid State Commun. **9**, 1041 (1971); J. Appl. Phys. **41**, 879 (1970).

37. E.J.W. Verwey and P.W. Haayman, Physica (Utrecht) **8**, 979 (1941); E.J.W. Verwey and E.L. Hailmann, J. Chem. Phys. **15**, 174 (1947); E.J.W. Verwey, P.W. Haayman, and F.C. Romeijn, ibid. **15**, 181 (1947).

38. S. Uchida, S. Tajima, H. Takagi, K. Kishio, T. Hasegawa, K. Kitazawa, K. Fueki, and S. Tanaka, *Proc. 18th Int. Conf. on Low Temperature Physics*, Kyoto, 1987; Jpn. J. Appl. Phys. **26**, 1105 (1987), Supplement 26-3.

39. S. Uchida, H. Takagi, H. Ishii, H. Eisaki, T. Yabe, S. Tajima, and S. Tanaka, Jpn. J. Appl. Phys. **26**, L440 (1987).

40. S. Tajima, S. Uchida, S. Kanbe, K. Kitazawa, K. Fueki, and S. Tanaka, Jpn. J. Appl. Phys. **26**, L432 (1987).

41. V.Z. Kresin, G. Deutscher, and S.A. Wolf, J. Superconductivity **3** (1988), to appear.

42. R. Aoki, S. Takahashi, K. Sakai, T. Nakamura, K. Kawasaki, and R. Liang, Parity **3**, 55 (1988).

CURRENT JAPANESE SUPERCOMPUTERS FOR COMPUTATIONAL FLUID DYNAMICS APPLICATIONS

Hideo Yoshihara

Current top-of-the-line Japanese supercomputers are described, stressing the vector features significant for highly vectorized computational fluid dynamics (CFD) codes. Covered are the Fujitsu VP4OOE, Hitachi S820, and NEC SX-2A computers. A benchmarking of these computers, scheduled in the near future, is described using the Navier/Stokes calculation over a delta wing with about one million mesh points.

INTRODUCTION

Computational fluid dynamics (CFD) is rapidly becoming an important design tool for advanced aerospace vehicles. Consider the case of the aerospaceplane currently in design in both the United States and Japan and in several European countries. Here CFD serves not only as an essential design tool but as the only available tool in an important segment of the flight where ground test facilities are incapable of producing the correct pressure and temperature environment. Laminar/turbulent transitional flow also assumes a greatly increased role at the high altitude/high mach number portion of the flight. Since turbulence at hypersonic mach numbers is a compressible phenomenon, existing established transition theories based on incompressible turbulence become inapplicable. Here the direct or large eddy simulation method now assumes an important role, since the alternative of acquiring empirical modeling data at hypersonic conditions to formulate an applicable transition method is discouragingly difficult. Such modeling data are not needed in direct or large eddy simulation since the Navier/Stokes (laminar) equations are solved directly using adequately refined time and space discretizations to resolve the turbulence.

CFD could not serve as a usable design tool without powerful supercomputers with large memories. Problems as described above require enormous computing times. Moreover, as flow algorithms and supercomputers improve, the additional capability is used, not to reduce the computer costs but to treat even more realistic configurations with improved flow modeling. The need for improved algorithms and computers thus does not abate. Improvements in the algorithm must be continually sought, always programming the code in a manner best using the improving computer architecture. To be effective, the programmer must thus be familiar with the architectural features of the supercomputer.

In the following, the architectural features of current supercomputers in Japan are described with a bias towards CFD applications that are highly vectorizable. Here the importance of a balanced architecture must be kept in mind where the size and makeup of the memory, the memory/vector register bandwidth, the number and capacity of the registers, and the processor speed are kept compatible.

CURRENT JAPANESE SUPERCOMPUTERS

Supercomputer manufacturers in Japan are Fujitsu Ltd., Hitachi Ltd., and NEC Corp. These companies are significantly smaller than Cray Research Inc. as measured by the number of supercomputers delivered. In the following the architectural features of the top-of-the-line Fujitsu VP4OOE, Hitachi S820, and NEC SX-2A are given. These computers are all single central processing unit (CPU) machines in contrast to current U.S. computers, which are primarily multiple-CPU machines. In the brief descriptions to follow, the emphasis will be on the vector features of the supercomputers, since viscous flow CFD programs of interest are highly vectorizable.

Fujitsu VP4OOE

The VP4OOE is the improved version of the VP4OO and is the most powerful in the Fujitsu FACOM series of computers, which have been noted for their ease of use. (In Japan, Fujitsu supercomputers are commonly identified by the acronym FACOM standing for Fujitsu Automatic Computer.) In Figure 1 the block diagram for the VP4OOE is shown. It is a single-CPU machine with a processor clock time of 7.0 nanoseconds (ns) and a peak processing speed of 1.7 gigaflops (GF). The VP4OOE has a 256-megabyte (MB) main memory that can be supplemented with up to 768 MB of vector memory, that is, a total memory of up to 128 megawords (MW) or half of the Cray 2 basic main memory. The bandwidth between memory and vector registers is 5.57 gigabytes per second (GB/s) via a single load/store pipe. The CPU contains five pipes: multiply/add/logical, add/logical, divide, mask, and load/store. The pipes can be chained, and four out of five pipes can operate concurrently.

The earlier VP4OO differs from the VP4OOE primarily in the slower processor speed of 1.067 GF, a smaller memory of 256 MB, and the deletion of the add/logical pipe chained to the multiply pipe. Both the VP4OO and VP4OOE have the same single load/store pipe between vector registers and memory, and this is to be contrasted with the VP2OO, next lower in the FACOM series, which has two (concurrent) load/store pipes but with the same total bandwidth as the VP4OOE. As compared to the VP4OO, the VP2OO has one-half the vector processing speed but the same main memory. For highly vectorized codes, full advantage of the greatly increased speed of the VP4OOE cannot be fully used because of the restrictive bandwidth between memory and vector register. It would thus appear that the VP4OOE was intended to be an interim machine with a greatly increased memory.

The compiler for the VP4OOE is fully Fortran 77 compatible, and an extended Fortran language, Fortran 77/VP, provides automatic vectorization of nested DO loops, for example, containing IF statements and gather/scatter operations. To supplement Fortran 77/VP, an additional tool, Interactive Vectorizer, permits the user to further tune the compiler interactively. (Experienced programmers apparently bypass such devices.) FORTUNE is a diagnostic tool detailing the execution costs. Interactive debugging assist tools include TESTFORT 77 and DOCK/FORTRAN 77, the latter with a full screen display.

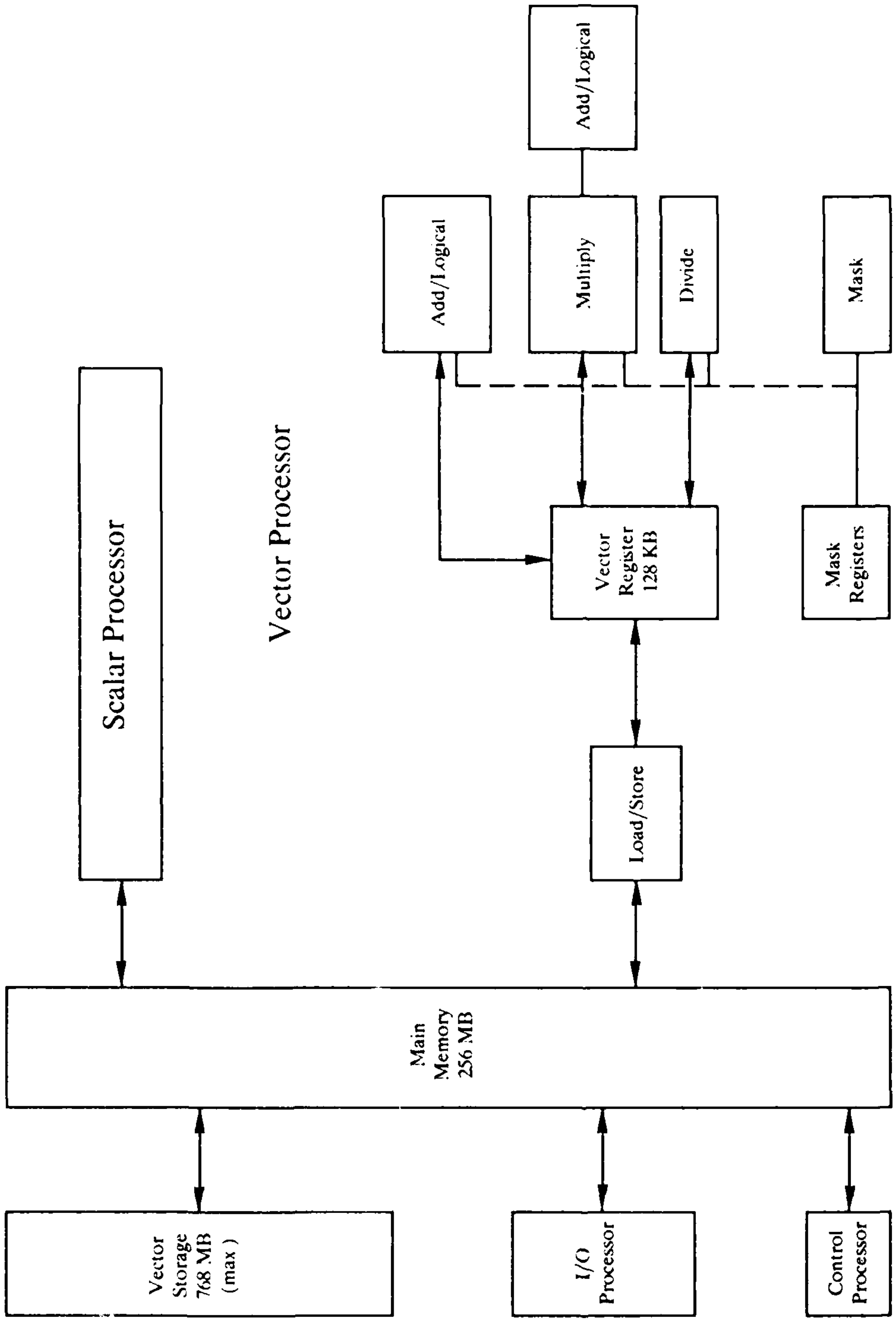


Figure 1. Fujitsu VP400E.

At present two VP4OOE computers are in operation, one at Kyoto University and the other at the Recruit Company in Tokyo, a time leasing company. With respect to the aeronautical institutes, the earlier VP4OO is installed at the National Aerospace Laboratory (Japan's NASA) and the VP2OO is in operation at the Institute for Space and Astronautical Sciences (ISAS).

Hitachi S820

The Hitachi S820 is the latest and fastest Japanese supercomputer. Its primary architectural features are given in Figure 2. The vector cycle time is a fast 4 ns with a maximum processing speed of 3 GF. For CFD applications, a lower speed of 2 GF has been suggested because of the memory/vector register bandwidth of 2 GB. The vector CPU is composed of four add/logical and four multiply/add fully segmented pipes, one divide, and one mask pipe. These pipes can be chained. The connection between memory and registers is via four vector load and four vector load/store pipes that can operate concurrently. The main memory has a capacity of 512 MB. An extended solid state storage of up to 12 GB can be added with a bandwidth between this storage and main memory of 2 GB/s. The extended Fortran compiler used is the FORT77/HAP compiler, which automatically vectorizes loops containing IF statements and gather/scatter operations. It can enhance the vector performance of nested loops by splitting, unrolling, or interchanging loops.

With respect to CFD users, a Hitachi S820 has been installed at the Hongo campus of the University of Tokyo, at the University of Hokkaido, and at the Institute for CFD, a private company in the southern suburbs of Tokyo operated by Professor K. Kuwahara of ISAS. Overall, the Hitachi S820 is an outstanding supercomputer.

NEC SX-2A

The primary hardware features of the SX-2A are given in Figure 3. This supercomputer has a peak speed of 1.3 GF. It also is a one-CPU machine with 16 independent vector pipes, that is, four sets of pipes each set containing add, multiplication/division, logical, and shift pipes. These pipes are automatically chained for optimal vector performance. The main memory has a capacity of up to 1 GB and can be supplemented by an extended solid state storage of up to 8 GB. The transfer rate between the main and extended memory is 11 GB/s.

There are four paths between the memory and vector register with a total bandwidth of 11 GB/s. This is specified as equivalent to transferring 1.3 billion 64-bit floating point data per second, and this bandwidth exactly matches the speed of the vector processor.

The FORTRAN77/SX compiler for the SX-2A automatically vectorizes DO loops containing IF statements, intrinsic functions, and list vectors. The vector performance can be enhanced through two user tools, namely, the ANALYZER/SX, which analyzes a program's static and dynamic characteristics, and the VECTORIZER/SX, which can be used interactively to increase the vectorization.

The NEC SX-2, an earlier model, is installed, for example, at Osaka University, Tohoku University (Sendai), and at the Institute for CFD. (The SX-2 is essentially the same as the SX-2A except for a smaller memory of 256 MB.) The SX-2A is a well-balanced machine.

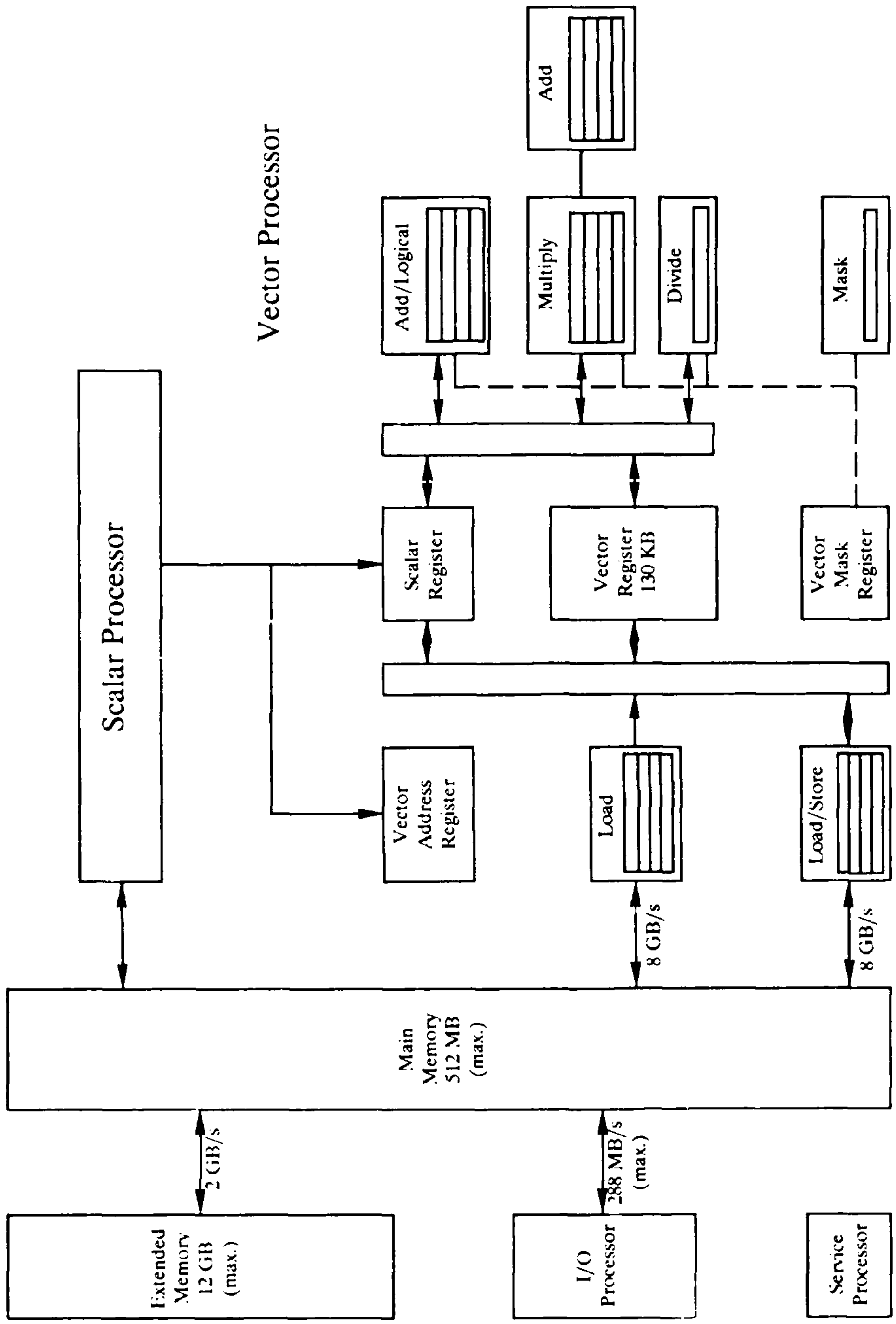


Figure 2. Hitachi S-820.

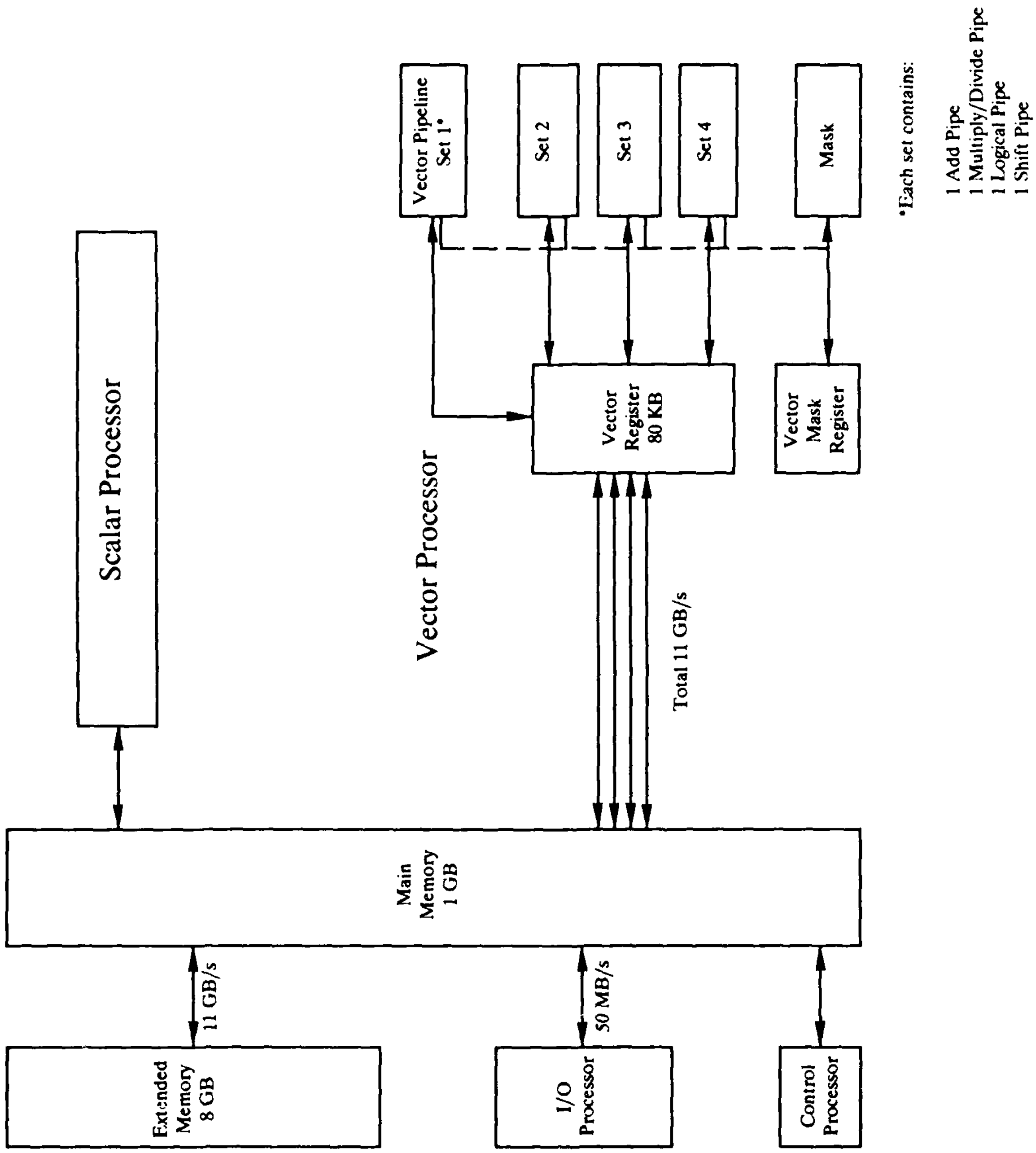


Figure 3. NEC SX-2A.

FINAL REMARKS

All three Japanese supercomputers are without question outstanding computers with large memories and speeds in the gigaflop range.

For these single-CPU machines, the phenomenal peak processor speeds have been achieved by using many concurrent pipes in the vector processor. Computational rates for a given CFD problem, however, cannot approach such speeds unless the vector processing pipes are kept continuously filled. This requires an algorithm with a high degree of vectorization, a sufficiently large versatile memory, and a nonconstricting bandwidth between memory and processor including compatible vector registers.

The single-CPU Japanese computers are in contrast to current multi-CPU U.S. supercomputers such as the Cray YMP computer with eight CPUs, each processor having two add/subtract, two logical, one shift, one multiply, and one reciprocal pipe. This difference in architectural approach may be explained in part by the difference in the user environment. In Japan the number of users performing large-scale computations is significantly less than in the United States, and the fast single-CPU machines are sufficient, at least for the immediate requirements. On the other hand, in the United States with a much larger number of users carrying out large computations, a multiple-CPU machine is more suitable, since the many users can be accommodated using the CPUs independently. Moreover, for users with very large problems (that is, hundreds of hours of computing), the CPUs can be used in appropriate combinations through multitasking to reduce the computing time to a more responsive level.

The Japanese computer firms up to the present have not strongly promoted sales outside Japan. This is changing. In the Fujitsu VP4OOE, Hitachi S-820, and NEC 2XA, the operating systems have been made UNIX compatible, in part for the U.S. market. Moreover, the new computers to be announced by Fujitsu and NEC in the near future are rumored to be multiprocessor machines, again suggesting a targeting of U.S. markets. (Rumors are prevalent since Japanese supercomputer companies are reluctant to announce new products until both hardware and software have been fully checked out.)

In the near future, a benchmarking of the above Japanese supercomputers will be carried out. Instead of the usual computing kernels, a three-dimensional Navier/Stokes calculation over a delta wing will be used with a mesh of about one million points. This approach was taken since the use of the Navier/Stokes code will not only exercise all aspects of the computer but will yield valuable information on a code that will be widely used in the coming decade. In a benchmark exercise, the merits of the supercomputer and the skill of the programmer must be carefully distinguished. Benchmarks will therefore be obtained for two cases: the first for the Navier/Stokes code as furnished, and the second with code modifications permitted by the participants to improve the performance. Fortran-compatible compiler tuning will be permitted. Timing breakdowns will be noted, for example, for the CPU time, data transfer times, as well as the input/output (I/O) time for throughput assessment. Each participant will describe the code improvements and compiler tuning used.

Cray Research Japan Inc. has also agreed to participate in this benchmarking using the 8-CPU Cray YMP. The benchmark results of the above Japanese supercomputers and the Cray YMP will be completed in early 1989. It is anticipated that benchmarks for the rumored new supercomputers from Fujitsu and NEC will be completed during the summer of 1989.

There are pitfalls in the benchmarking process for supercomputers. Thus by itself, a performance comparison of the single-CPU (but many piped) Japanese supercomputers with the 8-CPU Cray YMP or in a reverse sense with the Cray YMP with a single CPU is meaningless. In selecting a computer, factors other than a benchmark clearly must be taken into account, such as the cost of the computer and its user environment. However, of more importance to the CFD community are the method and approach used in the compiler tuning and code improvements by the participating programming experts.

The above benchmark exercise will be a joint effort with Professor K. Fujii of the Institute of Space and Astronautical Sciences who will provide his Navier/Stokes code, the geometry, and mesh for the delta wing.

ACKNOWLEDGMENTS

Discussions with Dr. Yoshio Tago, manager of the Scientific Systems Engineering Group of Fujitsu Inc.; Mr. Shun Kawabe, senior engineer of the Computer Development Department of Hitachi Inc.; and Mr. Shinichi Mineo, supervisor of the Third Systems Support Department of the NEC Corp., are gratefully acknowledged. Mr. Yoshikazu Hori, president of Cray Research Japan Inc., kindly provided information on the Cray YMP.

Hideo Yoshihara arrived in Tokyo in April 1988 for a 2-year assignment as a liaison scientist for the Office of Naval Research. His assignment is to follow the progress of advanced supercomputers and to review and assess the viscous flow simulation research in the Far East. Dr. Yoshihara formerly was with the Boeing Company, where he was Engineering Manager for Applied Computational Aerodynamics. He was also an affiliate professor in the Department of Aeronautics and Astronautics of the University of Washington, an AIAA Fellow, and a former member of the Fluid Dynamics Panel of AGARD/NATO.

INTERNATIONAL SYMPOSIUM ON STRATEGY OF INNOVATION IN MATERIALS PROCESSING (SIMAP '88)

E.A. Metzbower

At the International Symposium on Strategy of Innovation in Materials Processing, the sessions reflected the depth and breadth of the research efforts at the Welding Research Institute. These sessions were in the following areas: creation and processing of high function materials, surface modification, biomaterials, new joining processes for advanced materials, utilization of computers, and future structures.

An international symposium on Strategy of Innovation in Materials Processing--New Challenge for the 21st Century (SIMAP '88) was held 17 and 18 May 1988 at the newly dedicated Arata Hall of the Japanese Welding Research Institute at Osaka University. Professor Emeritus Yoshiaki Arata, in the preface to the symposium proceedings, states that his hope is that "many people will participate in this symposium to study the state of the arts, to discuss the future trends, and to visualize strategy for innovation in materials processing among people not only in Japan but also world wide." The symposium was attended by over 200 people with about 40 of these from outside of Japan.

The six sessions of the symposium reflected the depth and breadth of the research efforts at the Welding Research Institute. The six sessions were as follows:

1. Creation and Processing of High Function Materials

2. Surface Modification

3. Biomaterials

4. New Joining Processes for Advanced Materials

5. Utilization of Computers

6. What We Can Do for the Future Structures

The symposium started with an excellent presentation by Professor Julian Szekley of the Massachusetts Institute of Technology titled "New Developments in Speciality Metals Processing--The Role of the Science Base." Prof. Szekley used the "S" curve as a means of describing the relationship between effort and performance. The "S" curve has a lower shelf or level followed by a rapid transition to an upper shelf or level. Using this device he indicated that certain technologies, e.g., electroslag remelt (ESR), vacuum arc remelt (VAR), plasma arc remelt (PAR), had reached the top of the curve and only a small increase in performance could be obtained for any increase in effort. On the other hand, such technologies as spray

forming and plasma cold hearth remelting are in the center of the curve and a large increase in performance could be obtained for any increase in effort. Other technologies, such as composites and cold crucible induction melting, are on the bottom shelf of the "S" curve and considerable effort will be required to enhance their performance. Obviously performance and effort are parameters that could easily be replaced by a host of other parameters such as utilization and time. This concept was then applied to plasma systems, melt behavior, atomization, and solidification processing.

During my presentation on "The Role of Lasers in Modern Materials Processing," I reviewed the use of high power, continuous wave lasers in materials processing and indicated areas in which lasers are expected to contribute significantly in the near and far future both by modifications and improvement in lasers as well as a better understanding and use of the laser as a unique heat source.

Professor R. Yamamoto from the University of Tokyo gave the next presentation titled "Superlattices and Their Applications." The presentation centered on the production and properties of multilayered films or artificial superstructure films. The control of such films is almost on the atomic scale and the creation of these films appears to be a time consuming and experimentally difficult process. The author states that "at present it is not clear which material and fabrication parameters determine the growth and properties of a superstructure in a certain metal." Clearly this technology has a long way to go before it is used commercially.

The session on surface modification began with a presentation by Professor H.D. Steffens of the University of Dortmund titled "Arc and Plasma Spraying Today and in the 9Oth." Prof. Steffens reviewed the area of coatings by spraying techniques, concentrating on current and future applications. In view of the continually increasing construction material requirements and the increasing expense of materials with special properties such as high resistance to corrosion and wear, thermal spraying methods, such as plasma and arc spraying, are becoming more and more important. In his paper, Prof. Steffens reviewed the operating principles, current and future application fields, as well as the latest operational variants of these methods.

Dr. Muryel Wehr, Centre de Recherches de la Compagnie Generale d'Electricite, gave the next presentation on the "Formation of Ceramic Coatings by Laser Processes." In this work, in which Dr. Wehr collaborated with Professor A. Matsunawa of the Welding Research Institute, the different techniques used for the formation of ceramic coatings with a Nd:YAG laser as a heat source were described as well as the present and projected use of these coatings. Dr. Wehr concluded that for wear applications, powder deposition methods, pyrolytic laser chemical vapor deposition (LCVD), and laser pressure vapor deposition (LPVD) are the most appropriate. The LPVD process allows the deposition of all types of ceramics, while the LCVD process is only possible for materials having gas or high pressure liquid reactant sources.

The concluding paper in this session was "Formation of High Function Ceramic Surface by Ion Implantation," by Professor N. Iwamoto, the director of the Welding Research Institute. Prof. Iwamoto described his research to fabricate a SiC-SiN composite material using the ion implantation technique with nitrogen ions. He concluded that migration of nitrogen inside the implanted volume occurred after heat treatment and that depending on the implanting condition, the occurrence of the formation of carbonitride was detected, but that the heat treatment temperature was critical.

The concluding session of the day was on biomaterials. In the first paper, "Recent Progress on the Science of Biomedical Polymeric Materials," Professor K. Takemoto of Osaka University gave an enlightening presentation on the biomedical polymeric materials that have been developed, especially focusing on contact lenses, dental polymers, artificial skin, liver, kidney, heart, etc. The problems associated with their uses were also discussed. The emphasis in this review was on materials that have been fully developed. The materials were divided into three areas: (1) biomedical polymeric materials that have little contact with blood, such as contact lenses; (2) materials that are in contact with blood but only for a short time, such as artificial kidneys; and (3) materials that are in contact with blood for long periods of time, such as an artificial heart.

Professor H. Aoki of the Tokyo Medical and Dental University presented a paper titled "Hydroxyapatite of Great Promise for Biomaterials," in which he described some clinical experiments on dogs using hydroxyapatite for dental and surgical uses. Among the projected uses of hydroxypatite are: artificial bones and joints, bone filler, artificial blood vessels and tracheal, dentifries, tooth root, and teeth. His presentation was highlighted by a set of excellent color slides of the clinical trials.

Session 4 was on new joining processes for advanced materials. The first presentation, by Professor David Dickinson of Ohio State University, was titled "Future Trends for Joining of Advanced Materials--A Report on Research Activities in Advanced Materials and Processes at Ohio State University." Prof. Dickinson gave a thorough overview of the many different research programs in the Welding Engineering Department at Ohio State aimed at using advanced materials and advanced joining processes. The challenge that the 21st century offers to industry, to effectively use the newer advanced materials and processes to produce better, more economical welded and bonded products at reduced costs, was a recurring message in the presentation.

Dr. C.J. Thwaites from the International Tin Research Institute, U.K., gave an interesting presentation on "Soldering Microelectronic Assemblies: Some Problems and Studies." This seemingly mundane field has some unique problems associated with it, and as was pointed out, very little basic research is being done in this area. There is, however, a program in this field at the Welding Research Institute under Professor Okamoto. Dr. Thwaites pointed out that the provision of highly solderable surfaces of component terminations and circuit boards is still a primary requirement for reliability. Checking of solderability of components is desirable,

but methods for this have not been perfected because of the small size of the components. Visual inspection is becoming extremely difficult, if not impossible, and reliance must therefore be placed on using surfaces of good solderability and close control of the soldering processes.

Professor E.R. Wallach of Cambridge gave an excellent talk on "Progress of Diffusion Bonding of Various Materials," in which the various proposed mechanisms of diffusion bonding were reviewed and the different models of the process were discussed. Diffusion bonding is finding increased industrial applications in joining such diverse materials as superplastic metallic alloys, metal matrix composites, and the new high critical temperature ceramic superconductors. Bond assessment by mechanical testing and nondestructive evaluation as well as microscopy of the joint area was also discussed.

"Utilization of Computers" was the title of the fifth session. The first presentation was on "Color Vision for Road Following," by Professor C. Thorpe of Carnegie Mellon University. Prof. Thorpe talked about the problems involved with the sensing of a road and directing a vehicle over the correct path in real time. The interpretation of the path and the problems associated with such things as shadows, snow, rain, etc. were well covered in this interesting presentation. Parallel processing has been incorporated into the computational scheme.

The next presentation was titled "The Trends in Supercomputers," by Mr. M. Maruyama of Century Research Center, Japan. This technically oriented presentation delved into such items as scalar versus vector processing and the many applications of supercomputers in today's research. Improvements in the speed of supercomputers are limited because of the propagation speed of an electronic pulse in a wire. One direction for future systems is multiprocessors. The difficulty with that approach is the development of efficient software.

The last presentation in this session was by Professor J.L. Pan of Tsinghua University, China, on the "Future Direction of Welding Structure Production." The author pointed out the relationship between steel production and the most prosperous industries of developed countries in different ages and stated that welding will play an important part in heavy industries for many years to come. The automation of these processes is critical. The development of computer-aided design (CAD), computer-aided manufacturing (CAM), and the sensing devices that can be instrumented to the computer will lead to a true artificial intelligence (AI) for welding.

Session 6 was titled "What We Can Do for the Future Structures." Dr. P.R. Kasten of Oak Ridge National Laboratory presented "Very High Temperature Reactors for Future Use," in which he described the concept of modular reactors and how they could be improved by raising the temperature so that their efficiency is greatly improved. The material problems associated with these reactors were stressed. At these higher temperatures fossil fuel conversion can be used.

Dr. A. Kitamura from Ishikawajima-Harima Heavy Industries presented "Of Present and Future Space Structures, Their Materials and Construction." This paper stressed the need to develop new lightweight materials that can be used for space structures.

The symposium went from outer space to the depths of the oceans with the presentation titled "Materials for Deep Submergence Research Vehicle" by Dr. K. Yokota of Mitsubishi Heavy Industries. Dr. Yokota discussed the material problems associated with the design and construction of SHINKAI 2000, a submergence research vehicle that can operate at depths up to 2,000 meters, and its successor under construction, a submergence research vessel that can go as deep as 6,000 meters. The primary metal in the hull is a titanium alloy (Ti-6Al-4V ELI).

The final presentation at the symposium was by Mr. H. Nakashima of the Railway Technical Research Institute on "Magnetically Levitated Vehicles by Superconducting Magnets." This prototype system has been developed to propel a railroad car at speeds up to 300 km/h.

Edward A. Metzbower is a supervisory metallurgist in the Materials Science and Technology Division of the Naval Research Laboratory (NRL) in Washington, DC. A graduate of Loyola College and the Johns Hopkins University, Dr. Metzbower has been employed at NRL since 1967. Currently, as head of the Welding Metallurgy Section, he is involved in a program studying the relationships between the mechanical properties, micro- and macro-structures, and processing parameters of laser beam welding. He is a fellow of the Welding Institute, on the Board of Directors of the Laser Institute of America, chairman of the Electron and Laser Beam Committee of the Joining Division Council of ASM International, and a member of the High Density Cutting and Welding Committee of the American Welding Society.

INTERNATIONAL MEETINGS IN THE FAR EAST
1989-1994

Compiled by Yuko Ushino

Yuko Ushino is a technical information specialist for ONR Far East. She received a B.S. degree from Brigham Young University at Provo, Utah.

The Australian Academy of Science, the Japan Convention Bureau, and the Science Council of Japan are the primary sources for this list. Readers are asked to notify us of any upcoming international meetings and exhibitions in the Far East which have not yet been included in this report.

1989

Date	Title/Attendance*	Site	Contact for Information
January 3-9	International Conference on Nuclear Reaction Mechanism	Calcutta, India	Suprokash Mukherjee Saha Institute of Nuclear Physics Sector 1, Block AF, Bidhan Nagar Calcutta 700 064
January 10-13	The 5th International Conference on Ferrites	Bombay, India	Professor C.M. Srivastava, Head Advanced Center for Research in Electronics (ACRE) Indian Institute of Technology (IIT) Bombay 400076
January 19-20	National Conference on Industrial Tribology-89	Trivandrum, India	
January 30- February 3	The 2nd NCB International Seminar on Cement and Building Materials	New Delhi, India	The Organizing Secretary 2nd NCB International Seminar National Council for Cement and Building Materials M 10 South Extension II Ring Road, New Delhi 110049
January 31- February 3	The 17th Australian Polymer Symposium	Brisbane, Australia	Dr. D.J.T. Hill Chemistry Department University of Queensland Brisbane 4067 QLD
February 1-5	International Symposium on Industrial Metal Finishing	Tamilnadu, India	Dr. S. Guruviah Central Electrochemical Research Institute Karaikudi 623006 Tamilnadu, India

*Note: Data format was taken from the Japan International Congress Calendar published by the Japan Convention Bureau.

No. of participating countries
F: No. of overseas participants
J: No. of Japanese participants

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
February 5-6	Advances in Biomedical Polymers	Perth, Australia	The Secretary, W.A. Polymer Group Royal Australian Chemical Institute 125 Hay Street Perth, WA 6000 Australia
February 8-10	International Conference on Base Metals Technology	Jamshedpur, India	Secretariat: BMT-89 c/o Mr. D.D. Akerkar Deputy Director National Metallurgical Laboratory PO Burmanines, Jamshedpur 831007
February 14-17	The 4th International Photovoltaic Science and Engineering Conference	Sydney, Australia	Secretariat 2 New McLean Street P.O. Box 79 NSW 2027
March 12-16	International Symposium/ Information Transduction and Processing in Biological Systems - From Cell to Whole Body 8-F60-J190	Takamatsu, Japan	Department of Physiology Kagawa Medical School 1750 Ikenobe, Miki-cho Kita-gun, Kagawa-ken 761-07
March 14-16	The 1st JHPS International Symposium on Fluid Power 5-F50-J100	Tokyo, Japan	Japan Hydraulics and Pneumatic Society 3-5-8 Shiba-koen Minato-ku, Tokyo 105
March 15-17	International Workshop on Intelligent Materials	Tsukuba, Japan	Secretariat: International Workshop on Intelligent Materials The Society of Non-Traditional Technology Toranomon Kotohira-Kaikan Bldg, 3F 1-2-8 Toranomon Minato-ku, Tokyo 105 Attn: Mr. Tsunehisa Kurino
April 3-5	International Symposium for Electromachining 16-F100-J300	Nagoya, Japan	Institute of Industrial Science University of Tokyo 7-22-1 Roppongi Minato-ku, Tokyo 106
April 3-7	IFIP TC-2 Working Conference on Visual Database Systems 15-F30-J60	Tokyo, Japan	Professor Tosiyasu L. Kunii Department of Information Science Faculty of Science, University of Tokyo 7-3-1 Hongo Bunkyo-ku, Tokyo 113
April 10-12	International Workshop on Industrial Applications of Machine Intelligence and Vision (MIV-89)	Tokyo, Japan	Professor Mitsuru Ishizuka Institute of Industrial Science University of Tokyo 7-22-1 Roppongi Minato-ku, Tokyo 106
April 10-13	The International Symposium for Electromachining 15-F100-J300	Undecided	The Institute of Electrical Engineers of Japan Gakkai Center Building 2-4-16 Yayoi Bunkyo-ku, Tokyo 113
April 10-14	1989 National Engineering Conference	Perth, Australia	
April 10-15	International Conference on Modernization of Steel Rolling	Beijing, People's Republic of China	ICMSR Secretariat Chinese Society of Metals 46 Dongsixi Dajie Beijing

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
April 11-14	International Symposium on Ship Resistance and Powering Performance (ISRP)	Shanghai, People's Republic of China	International Symposium on Ship Resistance and Powering Performance Department of Naval Architecture and Ocean Engineering Shanghai Jiao Tong University Shanghai
April 11-14	International Symposium for Electro-machining (ISEM 9) 16-F50-J300	Nagoya, Japan	Japan Society of Electrical-Machining Engineers c/o Institute of Industrial Science University of Tokyo 7-22-1 Roppongi Minato-ku, Tokyo 106
April 11-14	The 5th International Meeting of the Polymer Processing Society	Kyoto, Japan	Professor T. Matsuda Research Center for Medical Polymers and Biomaterials Kyoto University Shogoin, Sakyo-ku, Kyoto
April 12-14	The 22nd JAIF Annual Conference 25-F150-J1,100	Tokyo, Japan	Japan Atomic Industrial Forum, Inc. Toshin Bldg 1-1-13 Shimbashi Minato-ku, Tokyo 105
April 18-21	The 2nd Asian Fisheries Forum 30-F150-J150	Tokyo, Japan	Secretariat: The 2nd Asian Fisheries Forum c/o Faculty of Agriculture Tokyo University 1-1-1 Yayoi Bunkyo-ku, Tokyo 113
April 23-27	The 4th Wire Asia, Conference and Exhibition	Shanghai, People's Republic of China	Exhibitions for Industry Ltd. 110-112 Station Road East Oxted, Surrey RH3 0QA, UK
April 24-29	The 4th International Conference on Langmuir-Blodgett Films NA-F150-J300	Tsukuba, Japan	Dr. Kiroo Nakahara Secretary General of 4th-LB Conference Saitama University Urawa 338
April 25-28	The 9th International Conference on Nondestructive Evaluation in the Nuclear Industry	Tokyo, Japan	Member/Customer Service ASM International OH 44073 U.S.A.
April 26-28	International Symposium on Pressure Vessel Technology and Nuclear Codes & Standards	Seoul, Korea	Dr. Byung-Koo Kim Korea Advanced Energy Research Institute P.O. Box 7 Daeduk-Danji, Chungnam, Korea 301-353
May 9-12	The 2nd IMEKO TC 14 International Symposium on Metrology for Quality Control in Production	Beijing, People's Republic of China	
May 9-12	International Conference on Electrical Contacts and Electromechanical Components	Beijing, People's Republic of China	Professor Ji-Gao Zhang Beijing University of Posts and Telecommunications P.O. Box 109 Beijing
May 14-18	The 3rd World Conference on Neutron Radiography	Osaka, Japan	Research Reactor Institute, Kyoto University Kumatoricho, Sennan-gun, Osaka 590-04

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
May 17-19	The 10th International Workshop on Rare-Earth Magnets and Their Applications	Kyoto, Japan	Mr. T. Kurino c/o The Society of Non-Traditional Technology Toranomon Kotohira Kaikan Bldg, 3F 1-2-8 Toranomon Minato-ku, Tokyo 105
May 18-20	The 3rd Conference of Asian-Pacific Congress on Strength Evaluation	Yokohama, Japan	Professor Koji Shimizu Department of Mechanical Engineering Faculty of Engineering Kanto Gakuin University 4834 Mutsu-ura Kanazawa-ku, Yokohama 236
May 21-24	International Conference on Advanced Mechatronics	Tokyo, Japan	Japan Society of Mechanical Engineers Sanshin Hokusei Bldg 2-4-9 Yoyogi Shibuya-ku, Tokyo 151
May 22-25	1989 Symposium on VLSI Technology	Kyoto, Japan	Secretariat c/o Business Center for Academic Societies Japan Conference Department 3-23-1 Hongo Bunkyo-ku, Tokyo 113
May 22-25	The 7th French-Japanese Symposium on Medicinal and Fine Chemistry 2-F30-J80	Kurashiki, Japan	French-Japanese Society for Medicinal and Fine Chemistry c/o Faculty of Pharmacology Hokkaido University Nishi-6, Kita-12 Kita-ku, Sapporo 060
May 25-27	1989 Symposium on VLSI Circuits	Kyoto, Japan	Secretariat c/o Business Center for Academic Societies Japan Conference Department 3-23-1 Hongo Bunkyo-ku, Tokyo 113
May 29-31	1989 International Symposium on Multiple-Valued Logic (ISMVL-89)	Guangzhou, People's Republic of China	Dr. D.M. Miller Department of Computer Science University of Victoria P O. Box 1700 Victoria, B.C., Canada V8W2Y2
May 29-June 2	The 2nd International Near Infrared Spectroscopy Conference	Tsukuba, Japan	Dr. Sumio Kawano National Food Research Institute Kannondai, Tsukuba 305
June 5-8	International Symposium on Thermodynamic Analysis and Improvement of Energy Systems	Beijing, People's Republic of China	
June 6-7	IFIP WG10.2 Working Conference on the CAD Systems Using AI Techniques	Tokyo, Japan	Professor Gotaro Odawara c/o Business Center for Academic Societies Japan 3-23-1 Hongo Bunkyo-ku, Tokyo 113
June 12-15	The XXIII Yamada Conference on Nuclear Weak Process and Nuclear Structure	Toyonaka, Japan	Professor Masato Morita 1-1 Machikaneyama-cho Toyonaka-shi, Osaka 560

1989

Date	Title/Attendance	Site	Contact for Information
June 26-28	IUPAC International Symposium on Molecular Design of Functional Polymers	Seoul, Korea	Professor Sung Chul Kim Department of Chemical Engineering KAIST P.O. Box 131 Cheongyang, Seoul, Korea
July 2-7	The 27th International Conference on Coordination Chemistry	Gold Coast, Australia	UniQuest Limited University of Queensland St. Lucia, Queensland 4067
July 2-7	XXVII International Conference on Coordination Chemistry	Brisbane, Australia	Professor Clifford J. Hawkins Department of Chemistry University of Queensland Saint Lucia, Brisbane, Queensland 4067
July 3-5	1989 International Micro Process Conference (Micro Process '89)	Kobe, Japan	Secretariat c/o Business Center for Academic Societies Japan Conference Department 3-23-1 Hongo Bunkyo-ku, Tokyo 113
July 3-7	ICOMAT '89: The 6th International Conference for Martensitic Transformations	Sydney, Australia	ICOMAT '89 c/o N.F. Kennon Department of Metallurgy and Materials Engineering University of Wollongong P.O. Box 1144 Wollongong, NSW 2500, Australia
July 5-8	International Conference on Opto-Electronics Science and Engineering (ICOESE)	Beijing, People's Republic of China	Professor Sun Peimao Department of Precision Instruments Tsinghua University Beijing 100084
July 6-8	International Conference on Circuits and Systems (ICCAS '89)	Nangjing, People's Republic of China	Professor Wai-Kai Chen Department of Electrical Engineering and Computer Science University of Illinois at Chicago P.O. Box 4348 Chicago, IL 60680
July 9-14	The 4th International Conference on Scanning Tunneling Microscopy/ Spectroscopy (ICSTM/STS)	Oharai, Japan	Professor Osamu Faculty of Science Tokyo Institute of Technology 2-12-1 Ohokayama Meguro-ku, Tokyo 152
July 10-14	The 4th International Symposium of Plant Biosystematics (IOPB) 30-F80-J200	Kyoto, Japan	IOPB Symposium c/o Department of Botany Faculty of Science, Kyoto University Kitashirakawa Oiwake-cho Sakyo-ku, Kyoto 606
July 10-17	The 8th International Congress of Proto-Zoology	Tsukuba, Japan	Y. Nozawa Department of Biochemistry Gifu University 40 Tsukasamachi Gifu 500
July 11-14	The 1st China-Japan International Symposium on Instrumentation, Measurement and Automatic Control	Beijing, People's Republic of China	Professor Huang Jun-Qin Department of Automatic Control Beijing University of Aeronautics and Astronautics Beijing 100083

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
July 12-14	Topical Meeting on Solid State Lasers	Beijing, People's Republic of China	Professor Ue Peida University of Beijing Post and Telecommunications Beijing
July 17-20	The 8th International Conference on Alkali-Aggregate Reaction (8th ICAAR)	Kyoto, Japan	Dr. Toyoaki Miyagawa 8th ICAAR The Society of Materials Science, Japan 1-101 Yoshida Izumidono-cho Sakyo-ku, Kyoto 606
July 17-20	The 9th International Conference on Internal Friction and Ultrasonic Attenuation in Solids (ICIFUAS 9)	Beijing, People's Republic of China	Professor T.S. Ke Laboratory of Internal Friction and Defects in Solids Institute of Solid State Physics Academia Sinica Hefei
July 18-21	The 7th International Conference on Integrated Optics and Optical Fiber Communication (IOOC '89)	Kobe, Japan	7th International Conference on Integrated Optics and Optical Fiber Communication (IOOC '89) c/o Business Center for Academic Societies Japan 3-23-1 Hongo Bunkyo-ku, Tokyo 113
July 20-22	The International Conference on Machinery Moving Accuracy (Theory & Measurement)	Chongquing, People's Republic of China	
July 24-26	The 2nd Microoptics Conference/The 9th Topical Meeting on Gradient-Index Imaging Systems (MOC/GRIN '89)	Tokyo, Japan	Mr. Yasuhiko Noguchi Secretariat: MOC/GRIN '89 Banda Building 1-35-5 Yoyogi Shibuya-ku, Tokyo 151
July 31-August 4	The 2nd International Symposium on Plasticity and Its Current Applications 20-F70-J70	Tsu, Mie, Japan	Professor Masataka Tokuda Faculty of Engineering Mie University 1515 Kamihama-cho Tsu, Mie 514
August 11-13	International Conference on Constitutive Laws for Engineering Materials	Chongquing, People's Republic of China	
August 13-18	Solar Energy Congress Tokyo 1989 40-F600-J400	Tokyo, Japan	Japanese Section of International Solar Energy Society 322 San Patio 3-1-5 Takada-no-baba Shinjuku-ku, Tokyo 160
August 19-23	The 4th Asian Congress of Fluid Mechanics	Hong Kong	Professor N.W.M. Ko 4ACFM Secretariat c/o Department of Mechanical Engineering University of Hong Kong Pokfulam Road, Hong Kong
August 20-25	The 6th International Symposium on Novel Aromatic Compounds (ISNA-6) 20-F100-J300	Osaka, Japan	Chemical Society of Japan 1-5 Kanda-Surugadai Chiyoda-ku, Tokyo 101

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
August 20-25	The 9th International Conference on Crystal Growth (ICCG) 48-F250-J550	Sendai, Japan	Secretariat: 9th International Conference on Crystal Growth c/o Inter Group Corp. 8-5-32 Akasaka Minato-ku, Tokyo 107
August 21-26	The 14th International Conference on High Energy Accelerators	Tsukuba, Japan	Mr. Kitagawa National Laboratory for High Energy Physics 1-1 Ooho Tsukuba-shi, Ibaraki 305
August 22-25	1989 International Symposium on Antennas and Propagation, Japan (ISAP '89)	Tokyo, Japan	Dr. Takashi Katagi Mitsubishi Electric Corp. 325 Kamimachiya Kamakura 247
August 22-26	The 10th International Symposium on Nuclear Quadrupole Resonance Spectroscopy	Takayama, Japan	Dr. Tetsuo Asaji The Secretary of Xth ISNQRS Department of Chemistry, PC II Faculty of Science Nagoya University Chikusa, Nagoya 464-01
August 25-28	The 7th International Conference on Composite Materials (ICCM-7)	Beijing, People's Republic of China	Tu Dezheng China Society of Aeronautics and Astronautics 67 South Street Jiao Daokou, Beijing
August 26-31	The 7th International Summer School on Crystal Growth	Zao, Japan	Professor H. Komatsu ISSCG-7 Chairperson c/o Inter Group Corp. Akasaka Yamakatsu Bldg 8-5-32 Akasaka Minato-ku, Tokyo 107
August 27-31	The 3rd International Symposium on Foundation of Quantum Mechanics--In the Light of New Technology (ISQM-Tokyo '89) NA-F50-J60	Tokyo, Japan	Professor H. Ezawa Department of Physics Gakushuin University Mejiro, Toshima-ku, Tokyo 171
August 27-September 1	The 5th International Symposium on Microbial Ecology (5th ISME) 73-F600-J600	Kyoto, Japan	Organizing Committee of 5th International Symposium on Microbial Ecology c/o Inter Group Corporation 8-5-32 Akasaka Minato-ku, Tokyo 107
August 28-31	International Symposium on Computational Fluid Dynamics--Nagoya, 1989 (ISCF-Nagoya 1989)	Nagoya, Japan	Professor Michiru Yasuhara Department of Aerospace Engineering Nagoya University Furo-cho, Chikusa-ku, Nagoya 464-01
August 28-31	The 5th International Symposium on Robotics Research	Tokyo, Japan	Department of Mechanical Engineering Faculty of Engineering University of Tokyo 7-3-1 Hongo Bunkyo-ku, Tokyo 113
August 28-September 1	The 11th International Conference on Magnet Technology	Tsukuba, Japan	T. Haruyama National Laboratory for High Energy Physics Oho-machi, Tsukuba-shi, Ibaraki 305

1989			
Date	Title/Attendance	Site	Contact for Information
August 29-31	Perpendicular Magnetic Recording Conference '89 (PMRC '89)	Tokyo, Japan	Professor Masahiko Naoe Department of Physical Electronics Tokyo Institute of Technology 2-12-1 O-okayama Meguro-ku, Tokyo 152
August 29-September 1	The 2nd International Symposium on Antennas and EM Theory (ISAE '89)	Shanghai, People's Republic of China	Mao Yukuan Xidian University 2 Taibe Road Xi'an
September 4-8	The 2nd International Conference & Workshop on Electromagnetic Interference & Compatibility (INCEMIC)	Bangalore, India	Professor G.R. Nagabhushana High Voltage Engineering Dept. Indian Institute of Science Bangalore 560 0 12
September 4-8	The 7th International Conference on Liquid and Amorphous 30-F120-J280	Kyoto, Japan	Professor Hirohisa Endo Department of Physics, Faculty of Science Kyoto University Oiwake-cho, Kita-Shirakawa Sakyo-ku, Kyoto 606
September 4-8	ISES Solar World Congress 1989 Kobe 65-F400-J400	Kobe, Japan	Secretariat: ISES Solar World Congress 1989 c/o International Communications, Inc. Kasho Building 2-14-9 Nihonbashi Chuo-ku, Tokyo 103
September 5-7	International Conference on Zinc and Zinc Alloy Coated Steel Sheet 20-F50-J150	Tokyo, Japan	Secretariat of GALVATECH '89 Iron and Steel Institute of Japan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
September 6-8	ACD & D '89 International Symposium on Advanced Computers for Dynamics and Design '89	Tsuchiura, Japan	
September 8-10	1989 International Symposium on Electromagnetic Compatibility 26-F170-J430	Nagoya, Japan	Secretariat, International Symposium on Electromagnetic Compatibility c/o Department of Information and Computer Sciences Toyohashi University of Technology 1-1 Tenpaku-cho, Aza-Hibarigaoka Toyohashi, Aichi 440
September 9-14	The 2nd International Symposium on Rare Earths Spectroscopy	Changchun, People's Republic of China	Professor Su Qiang Changchun Institute of Applied Chemistry Academia Sinica Changchun 130022
September 11-12	Testing Electromagnetic Analysis Methods Workshops for Eddy Current Code Comparison 8-F30-J50	Okayama, Japan	Faculty of Engineering Okayama University 3-1-1 Tsushima-Naka Okayama 700
September 12-14	Thermtech Asia 89	Hong Kong	International Symposia and Exhibitions Ltd. Queensway House 2 Queensway Redhill, Surrey RH1 1QS, UK
September 17-22	International Conference on the Science and Technology of DEFECT CONTROL IN SEMICONDUCTORS-Yokohama 21st Century Forum	Yokohama, Japan	IC-STDCS c/o Lab. Physics of Crystal Defects Institute for Materials Research Tohoku University 2-1-1 Katahira, Sendai 980

1989

Date	Title/Attendance	Site	Contact for Information
September 17-22	The 40th Meeting of International Society of Electrochemistry 42-F200-J540	Kyoto, Japan	Secretariat 40th Meeting of International Society of Electrochemistry c/o Kyoto International Conference Hall Takaragaike, Sakyo-ku, Kyoto 606
September 22-25	The 3rd International Symposium on Defect Recognition and Image Processing for Research and Development of Semiconductors (DRIP III)	Tokyo, Japan	Professor Tomoya Ogawa Department of Physics Gakushuin University Mejiro, Tokyo 171
September 24-28	The 6th International Symposium on Passivity - Passivation of Metals and Semiconductors	Sapporo, Japan	Dr. Norio Satoh Faculty of Engineering Hokkaido University Nishi 8-chome, Kita 13-jo Sapporo-shi 060
September 25-28	The 5th International Conference on Numerical Ship Hydrodynamics 15-F80-J120	Hiroshima (tentative)	Faculty of Engineering Hiroshima University Shitami Saijo-cho Higashi-Hiroshima 724
September 25-29	The 16th International Symposium on Gallium Arsenide and Related Compounds	Karuizawa, Japan	Secretary: Professor T. Katoda Research Center for Advanced Science and Technology University of Tokyo 4-6-1 Komaba Meguro-ku, Tokyo 153
September 26-28	International Symposium on Optical Memory 1989	Kobe, Japan	Secretariat c/o Business Center for Academic Societies Japan 3-23-1 Hongo Bunkyo-ku, Tokyo 113
October 1-4	The 7th World Congress of the International Society for Artificial Organs	Sapporo, Japan	The 7th International Society for Artificial Organs c/o International Communications Inc. Kasho Bldg 2-14-9 Nihonbashi Chuo-ku, Tokyo 103
October 2-4	Today's Technology for the Mining and Metallurgical Industries 30-F300-J300	Kyoto, Japan	MMIJ/IMM Joint Symposium Office Mining and Metallurgical Institute of Japan Nogizaka Building 9-6-41 Akasaka Minato-ku, Tokyo 107
October 2-4	MMIJ/IMM Joint Symposium (Kyoto) 30-F300-J300	Kyoto, Japan	Mining and Materials Processing Institute of Japan Nogizaka Bldg 9-6-41 Akasaka Minato-ku, Tokyo 107
October 2-5	The 3rd International Conference on Computer Applications in Production and Engineering (CAPE '89)	Tokyo, Japan	Secretariat c/o Conference Department Business Center for Academic Societies Japan 3-23-1 Hongo Bunkyo-ku, Tokyo 113
October 3-5	The 10th Meeting of World Society for Stereotactic and Functional Neurosurgery 20-F200-J300	Maebashi, Japan	Department of Neurosurgery Gunma University, School of Medicine 3-39 Showa-machi Maebashi 371

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
October 15-18	The 9th International Display Research Conference - Japan Display '89 27-F200-J500	Kyoto, Japan	Secretariat of Japan Display '89 c/o Japan Convention Services. Inc. 4F, Nippon Press Center Bldg 2-2-1 Uchisaiwai-cho Chiyoda-ku, Tokyo 100
October 22-26	International Conference on Semiconductor and Integrated Circuit Technology	Beijing, People's Republic of China	Continuing Education in Engineering University Extension University of California 2223 Fulton Street Berkeley, CA 94720
October 22-28	1989 Joint Waste Management Conference	Kyoto, Japan	
October 23-27	International Conference on Coal Science	Tokyo, Japan	
October 24-26	Electric Energy Conference 1989	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600
October 26-28	ACEAN Polymer Symposium 10-F30-J30	Osaka, Japan	Institute of Scientific and Industrial Research, Osaka University 8-1 Mihogaoka Ibaraki-City, Osaka 567
November 6-10	Aluminum and Magnesium	Zhengzhou, People's Republic of China	Conference Office, IMM 44 Portland Place London W1N 4BR, UK
November 7-10	International Conference on Electronic Components and Materials (ICECM '89)	Beijing, People's Republic of China	Secretariat of ICECM '89 c/o Professor Zhou Zhigang Department of Chemical Engineering Tsinghua University Beijing 100084
November 7-10	The 2nd International Symposium on the Physical and Failure Analysis of Integrated Circuits	Singapore	Secretariat IPFA Symposium Communication International Associate Pte Ltd. 450 Alexandra Road #10-00 Inchcape House, Singapore 0511
November 14-16	The 1989 International Symposium on Noise and Clutter Rejection in Radar and Imaging Sensors (ISNCR-89)	Kyoto, Japan	Professor Tsutomu Suzuki Department of Electronics University of Electro-Communications Chofu-shi, Tokyo 182
November 20-23	International Conference Evaluation of Materials Performance in Severe Environments-Evaluation and Development of Materials in Civil and Marine Uses 20-F80-J120	Kobe, Japan	International Conference Secretariat Conference and Editorial Department Iron and Steel Institute of Japan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
November 20-December 1	The 1st International Symposium and Exhibition of SAMPE JAPAN CHAPTER	Makuhari, Japan	SAMPE P.O. Box 2459 Covina, CA 91722

1989

Date	Title/Attendance	Site	Contact for Information
November 22-24	Tencon 89	Bombay, India	Kirit J. Sheth, Chairman IEEE Bombay Section c/o Hakotoronics Pvt. Ltd. Dadoji Konddeo Cross Marg Bombay 400 027, India
December 11-15	The 10th Australasian Fluid Mechanics Conference	Melbourne, Australia	10AFMC c/o Professor A.E. Perry, Department of Mechanical Engineering The University of Melbourne Parkville, Victoria 3052

1990

Date	Title/Attendance	Site	Contact for Information
January 22-26	International Conference on Recrystallization in Metallic Materials	Wollongong, Australia	Metallurgical Society of AIME Conference Department 420 Commonwealth Drive Warrendale, PA 15086
April 8-12	1990 International Topical Meeting on Optical Computing	Kobe, Japan	OC'90 Secretariat Business Center for Academic Societies Japan (BCASJ) 3-23-1 Hongo Bunkyo-ku, Tokyo 113
May 19-26	The 27th International Navigation Congress 62-F500-J500	Osaka, Japan	Japan Organizing Committee for 27th International Navigation Congress of PIANC c/o Port and Harbor Bureau City of Osaka 2-8-24 Chikko Minato-ku, Osaka 552
July 1-6	The 3rd International Conference on Technology of Plasticity (3rd ICTP)	Kyoto, Japan	Professor Saichi Masaki Department of Mechanical Engineering Osaka Institute of Technology 5-16-1 Omiya Asahi-ku, Osaka 535
July 15-21	The 10th International Congress of Nephrology 10-F1,000-J4,000	Tokyo, Japan	Japanese Society of Nephrology c/o 2nd Department of Internal Medicine School of Medicine, Nippon University 30-1 Oyaguchi-kamicho Itabashi-ku, Tokyo 173
August 21-29	International Congress of Mathematicians 1990 84-F1,500-J1,500	Kyoto, Japan	ICM 90 Secretariat c/o International Relations Office Research Institute for Mathematical Sciences Kyoto University Kitashirakawa Oiwake-cho Sakyo-ku, Kyoto 606
August 23-30	V International Congress of Ecology 62-F900-J1,000	Yokohama, Japan	Secretary General's Office for INTECOL 1990 c/o Institute of Environmental Science and Technology Yokohama National University 156 Tokiwadai Hodogaya-ku, Yokohama 240
September 16-22	IUMS Congress - Bacteriology and Mycology - Osaka, Japan - 1990 71-F2,000-J600	Osaka, Japan	Preliminary Committee of International Congress of Microbiology c/o JTB Creative Inc. Daiko Building 3-2-14 Umeda Kita-ku, Osaka 530

1990

Date	Title/Attendance	Site	Contact for Information
September 24-27	The 6th International Congress on Polymers in Concrete	Shanghai, People's Republic of China	ICPIC-90 Secretariat c/o Associate Professor Tan Muhua Institute of Materials Science and Engineering Tongji University Shanghai
September (tentative)	The 15th International Congress on Microbiology 57-F2,500-J2,500	Osaka, Japan	Preliminary Committee of International Congress of Microbiology c/o JTB Creative Inc. Daiko Building 3-2-14 Umeda Kita-ku, Osaka 530
October 15-19	The 4th International Symposium on Marine Engineering (ISME KOBE '90)	Kobe, Japan	The Marine Engineering Society in Japan Hibiya Osaka 2nd Bldg 1-2-2 Uchisaiwai-cho Chiyoda-ku, Tokyo 100
October 21-26	The 6th International Iron and Steel Congress 50-F300-J500	Nagoya, Japan	International Conference Department Iron and Steel Institute of Japan 3F, Keidanren Kaikan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
1990 (tentative)	Chemeca 1990 Applied Thermodynamics	New Zealand	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600

1991

Date	Title/Attendance	Site	Contact for Information
February 10-15	POLYMER '91: International Symposium on Polymer Materials	Melbourne, Australia	Dr. G.B. Guise P.O. Box 224 Belmont, VIC 3216, Australia
August (tentative)	International Congress on Medical Physics 45-F600-J900	Kyoto, Japan	National Institute of Radiological Science 4-9-1 Anagawa Chiba 260
August (tentative)	The 16th International Conference on Medical and Biological Engineering (ICMBE)	Kyoto, Japan (tentative)	Japan Society of Medical Electronics and Biological Engineering 2-4-16 Yoyogi Bunkyo-ku, Tokyo 113

1992

Date	Title/Attendance	Site	Contact for Information
October 26-30	The 14th International Switching Symposium (ISS '92) 60-F1,200-J800	Yokohama, Japan	NTT Communication Switching Laboratories 3-9-11 Midori-cho Musashino-shi, Tokyo 180
Autumn	XIVth International Switching Symposium (ISS '92)	(to be decided)	Institute of Electronics, Information and Communication Engineers (IEICE) Kikai Shinko Kaikan 3-5-8 Shiba-koen Minato-ku, Tokyo 105

1993			
Date	**Title/Attendance**	**Site**	**Contact for Information**
1993 (tentative)	International Federation of Automatic Control Congress	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600

1994			
Date	**Title/Attendance**	**Site**	**Contact for Information**
Tentative	XXX International Conference on Coordination Chemistry	Kyoto, Japan	Professor Hitoshi Ohtaki Coordination Chemistry Laboratories Institute for Molecular Science Myodaiji-cho, Okazaki 444

SCIENTIFIC INFORMATION BULLETIN INDEX, VOLUME 13

AUTHORS

SUBJECTS

SUBJECTS (continued)

SUBJECTS (continued)

SUBJECTS (continued)

SUBJECTS (continued)

RESEARCH FACILITIES/ INSTITUTIONS

RESEARCH FACILITIES/ INSTITUTIONS (continued)

LOCATIONS

*U.S.GOVERNMENT PRINTING OFFICE:1988-241-575:80002

NOTICE

The Office of Naval Research/Air Force Office of Scientific Research/Army Research Office, Liaison Office, Far East is located on the second floor of Bldg #1, Akasaka Press Center and bears the following mail identification:

Mailing address:	Office of Naval Reseach/Air Force Office of Scientific Research/Army Research Office Liaison Office, Far East APO San Francisco 96503-0007
Local address:	ONR/AFOSR/ARO Far East Akasaka Press Center 7-23-17, Roppongi Minato-ku, Tokyo 106
Telephone numbers:	Civilian 03-401-8924 Autovon 229-3236 Telefax 03-403-9670

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. 12503 WASH., D.C.

POSTAGE WILL BE PAID BY DEPARTMENT OF THE NAVY

OFFICE OF NAVAL RESEARCH
LIAISON OFFICE, FAR EAST
APO SAN FRANCISCO 96503-0007